1999

Evaluation of concrete shrinkage and creep code models

Shoba Lakshmikantan
San Jose State University

EVALUATION OF CONCRETE SHRINKAGE

AND CREEP CODE MODELS

A Thesis

Presented To

The Faculty of the Department of Civil and Environmental Engineering

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Shoba Lakshmikantan

May 1999

UMI Number: 1394534

APPROVED FOR THE DEPARTMENT OF CIVIL AND

ENVIRONMENTAL ENGINEERING

Dr. Akthem Al-Manaseer

Mr. Ronald G. Burg

Dr. Thalia Anagnos

Dr. N. John Gardner

APPROVED FOR THE UNIVERSITY

ABSTRACT

EVALUATION OF CONCRETE SHRINKAGE AND CREEP CODE MODELS

by Shoba Lakshmikantan

Shrinkage and creep of concrete are time-dependent volume changes that can cause stresses, cracking and excessive deflection which profoundly affect the properties of concrete as a structural material. In this study, various prediction methods for shrinkage and creep of concrete are compared with the RILEM experimental data bank and evaluated by various statistical methods. This study reveals that the B3 model and the GZ model performed best for shrinkage strain, while the CEB 90 code model followed by the B3 model performed best for creep strain.

ACKNOWLEDGMENTS

The study described in this thesis was carried out in the Department of Civil and Environmental Engineering under the guidance of Dr. Akthem Al-Manaseer, Professor of Civil Engineering. I express my sincere respect, gratitude and thanks to Dr. Al-Manaseer for the contribution of his valuable time, guidance and encouragement during the entire duration of this study. This work would have never been possible, without his constant supervision and patience.

A great deal of thanks and respects are due to Dr. H.S. Muller for providing the RILEM data bank. I wish to express my deep appreciation to Dr. Z. P. Bazant, Dr. S. Baweja, Dr. D. McDonald and Dr. K. Sakata for their valuable inputs during the course of this work.

Further, my thanks are due to Dr. N. J. Gardner and Mr. Ronald G. Burg for reviewing this study and contributing valuable inputs.

I would like to thank Dr. Thalia Anagnos, Chairperson of the Department of Civil and Environmental Engineering, for reviewing this study and providing valuable comments.

Furthermore, my thanks are reserved for my husband Mr. S. Selvasekar for his guidance in the software programming, without which this extensive study is impossible.

Table of Contents

Nomenclature

A. Organizations

ACI	The American Concrete Institute
CEB-FIP	The Comite Euro-International Du Beton/Federation International de la Precontrainte-Europe

B. General Abbreviations and Symbols

R	=	European rapid hardening cement (assumed equivalent to type I cement)
SL	=	European slow hardening cement (assumed equivalent to type II cement)
RS	=	European rapid hardening high strength cement (assumed equivalent to type III cement)
Type I	=	North American normal Portland cement
Type II	=	North American moderate sulfate resistance cement
Type III	=	North American high early strength cement
$\varepsilon(t)$	=	Total strain (instantaneous plus creep plus shrinkage)
σ	=	Applied stress (psi)

C. Abbreviations and Symbols for Models

C.1 The ACI 209 Code Model

C_{cu}	=	Ultimate creep coefficient
$C_c(t)$	=	Creep coefficient at time t

E_{cmto}	=	Modulus of elasticity at age of loading (psi)
$f'_{c(28)}$	=	Mean 28-day concrete compressive strength (psi)
$f'_c(t_o)$	=	Mean concrete compressive strength at age of loading (psi)
H	=	Relative humidity (%)
K_{SH}	=	Relative humidity correction factor for shrinkage
K_{SS}	=	Shape and size correction factor for shrinkage
K_{CH}	=	Relative humidity correction factor for creep
K_{CS}	=	Shape and size correction factor for creep
K_{CA}	=	Age at loading correction factor
V/S	=	Volume-to-surface area ratio (in.)
t_o	=	Age of concrete at loading (days)
t	=	Time after loading (days)
t_s	=	Time after the beginning of shrinkage (days)
$\varepsilon_s(t)$	=	Shrinkage strain (in./in.)
ε_{shu}	=	Ultimate shrinkage strain (in./in.)
γ_χ	=	Unit weight of concrete (lb/yd^3)

C.2 The B3 Model

a/c	=	Aggregate-to-cement ratio by weight
c	=	Cement content of concrete (lb/ft^3)
$C_o(t,t')$	=	Compliance function for basic creep
$C_d(t,t',t_o)$	=	Compliance function for additional creep due to drying

$D = 2v/s$	=	Effective cross-section thickness (in.)
E_{28}	=	Modulus of elasticity at 28-days (psi)
f'_c	=	Mean 28-day concrete compressive strength (psi)
f_{ck}	=	Specified concrete compressive strength at 28-days (psi)
h	=	Relative humidity (decimal)
$H(t)$	=	Spatial average of pore relative humidity within cross section
$J(t, t')$	=	Creep compliance function
K_h	=	Humidity function for shrinkage
K_s	=	Cross section shape factor
q_1	=	Instantaneous strain due to unit stress
q_2	=	Aging visco-elastic compliance
q_3	=	Non-aging visco-elastic compliance
q_4	=	Flow compliance
$S(t)$	=	Time function for shrinkage
T_{sh}	=	Shrinkage half-time (days)
v/s	=	Volume-to-surface area ratio (in.)
w	=	Water content of concrete (lb/ft^3)
w/c	=	Water-to-cement ratio by weight
T	=	Age of concrete after casting (days)
t'	=	Age of concrete at loading (days)
t_o	=	Age of concrete at the beginning of shrinkage (days)
$\varepsilon_{sh\infty}$	=	Ultimate shrinkage strain (in./in.)

C.3 The CEB 90 Code Model

A_c	=	Cross-section area of member (in.^{2})
E_c	=	Modulus of elasticity at 28-days (psi)
$E_c(t_o)$	=	Modulus of elasticity at age of loading (psi)
f_{cm}	=	Mean 28-day concrete compressive strength (psi)
f'_{c28}	=	Specified concrete compressive strength at 28-days (psi)
$h_o = 2A_c/u$	=	Notional size of member (in.)
RH	=	Relative humidity (%)
t	=	Age of concrete after casting (days)
t_o	=	Age of concrete at loading (days)
t_s	=	Age of concrete at the beginning of shrinkage (days)
u	=	Perimeter of member in contact with atmosphere (in.)
$\beta_c(t - t_o)$	=	Coefficient to describe the development of creep with time after loading
$\beta_s(t - t_s)$	=	Equation describing development of shrinkage with time
$\beta(f_{cm})$	=	Factor to allow for effect of concrete strength on the notional creep coefficient (ϕ_o)
β_H	=	Coefficient to allow for the effect of relative humidity and the notional member size (h_o) on creep
β_{RH}	=	Coefficient to allow for the effect of relative humidity on the notional shrinkage coefficient (ε_{cso})

β_s	=	Coefficient to describe the development of shrinkage with time
β_{sc}	=	Coefficient depending on type of cement
$\beta(t_o)$	=	Factor to allow for the effect of age of concrete at loading on the notional creep coefficient (ϕ_o)
ε_{cso}	=	Notional shrinkage coefficient
$\varepsilon_{cs}(t - t_s)$	=	Shrinkage strain between time t and t_s
$\varepsilon_s(f_{cm})$	=	Factor to allow for the effect of concrete strength on shrinkage
ϕ_o	=	Notional creep coefficient
ϕ_{RH}	=	Factor to allow for relative humidity on the notional creep coefficient (ϕ_o)
$\phi(t - t_o)$	=	Creep coefficient defining creep between time t and t_o

C.4 The GZ Model

E_{cmto}	=	Mean modulus of elasticity at age of loading (psi)
E_{cm28}	=	Mean modulus of elasticity at 28-days (psi)
f_{ck28}	=	Specified concrete compressive strength at 28-days (psi)
f_{cm28}	=	Mean 28-day concrete compressive strength (psi)
f_{cmt}	=	Mean concrete compressive strength at age t (psi)
f_{cmto}	=	Mean concrete compressive strength at age of loading (psi)
f_{cmtc}	=	Mean concrete compressive strength at the beginning of shrinkage (psi)
h	=	Relative humidity (decimal)

K	=	Correction term for effect of cement type on shrinkage
t	=	Age of concrete after casting (days)
t_c	=	Age of concrete at the beginning of shrinkage (days)
t_o	=	Age of concrete at loading (days)
V/S	=	Volume-to-surface area ratio (in.)
$\varphi(t_c)$	=	Correction term for effect of drying before loading
$\beta(h)$	=	Correction term for effect of humidity on shrinkage
$\beta(t)$	=	Correction term for effect of time on shrinkage
ε_{sh}	=	Shrinkage strain (in./in.)
ε_{shu}	=	Ultimate shrinkage strain (in./in.)

C.5 The SAK Model

c	=	Cement content of concrete (kg/m^3)
$E_c(t_o)$	=	Modulus of elasticity at age of loading (N/mm^2)
RH	=	Relative humidity (%)
v/s	=	Volume-to-surface area ratio (mm)
w	=	Water content of concrete (kg/m^3)
t	=	Age of concrete after casting (days)
t'	=	Age of concrete at loading (days)
t_o	=	Age of concrete at the beginning of shrinkage (days)
$\varepsilon'_{cs}(t, t_o)$	=	Predicted shrinkage strain

ε'_{sh} = Ultimate shrinkage strain

$\varepsilon'_{cs}(t, t', t_o)$ = Predicted specific creep (mm^2/N)

ε'_{bc} = Basic creep (mm^2/N)

ε'_{dc} = Drying creep (mm^2/N)

D. Abbreviations and Symbols for Statistical Methods

D.1 The Average and Standard Deviation Methods

A_j = Average of residuals or compliance for fixed time j

n = Total number of values considered at a fixed time

S_j = Standard deviation of residuals or compliance for fixed time j

X_i = Residual or compliance value of i^{th} data point in a fixed time j

D.2 The B3 Coefficient of Variation ($\omega_{B3}\%$) Method

ϖ_j = Coefficient of variation for the data set number j

J_{ij} = Measured value of the compliance function or shrinkage strain of the i^{th} data point in data set number j

n = Number of data points in data set number j

n_w = Sum of the weights of all data points in a data set

n_k = Number of data points in the k^{th} decade

n_d = Number of decades on the logarithmic scale spanned by measured data in data set number j

N = Number of data sets in the data bank

Δ_{ij} = Deviation of the compliance function or shrinkage strain value given by the model from the measured value of the i^{th} data point in data set number j

ω_{ij} = Weights assigned to the the i^{th} data point in data set number j

ω_{B3} = Overall coefficient of variation of the deviations of the model from the measured values for all the data sets in the data bank

D.3 The CEB Coefficient of Variation (V_{CEB} %) Method

n = Number of differences (data points) taken for each experiment

N = Total number of data sets

S_i = Standard error determined from ΔY_{ij} of experiment i

V_i = Coefficient of variation of experiment i

V_{CEB} = Mean coefficient of variation

Y_i = Mean creep compliance or shrinkage strain of experiment i

Y_{ij} = Observed compliance function or shrinkage strain at time j of experiment i

ΔY_{ij} = Difference between observed shrinkage strain or compliance and predicted shrinkage strain or compliance at time j of experiment i, with the differences being taken at constant intervals along the log time axes

D.4 The CEB Mean Square Error (F_{CEB} %) Method and the Mean Deviation (M_{CEB}) Method

Cal X_{ij}	=	Predicted shrinkage strain or creep compliance of time j of experiment i
n	=	Total number of values j of experiment i considered at a fixed time
N	=	Total number of data sets
Obs X_{ij}	=	Experimental shrinkage strain or creep compliance of time j of experiment i
f_j	=	Percent difference between calculated and observed data point j
F_{CEB}	=	Mean square error
M_{CEB}	=	Mean deviation

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Shrinkage and Creep of Concrete

Shrinkage and creep are two important factors that affect the serviceability, durability and long term reliability of concrete structures. When a load is applied to a concrete specimen, the specimen first shows an instantaneous elastic deformation followed by a slow continual inelastic deformation. This slow increase of inelastic deformation was discovered in 1907 by Hatt,[1] and was called creep.

A concrete specimen also experiences volume changes throughout its life time even in the absence of applied loads. This deformational change is called shrinkage. There are three types of shrinkage strain. These are drying, autogeneous and carbonation. Drying shrinkage is due to moisture loss in the concrete. Autogeneous shrinkage is caused by the hydration of cement. Carbonation shrinkage is caused by the carbonation in the cement hydration products.

Creep strain can be divided into a non-drying component and a drying component. The non-drying component of creep is a time dependent increase in strain under a constant stress without any moisture gain or loss. It is also called basic creep. The drying component of creep is a time dependent increase in strain under drying conditions and is called drying creep. The terms creep coefficient, specific creep or creep compliance are generally used to describe creep strain by different models. The creep coefficient is defined as the ratio of creep strain (i.e. basic creep plus drying creep) at a given time to the elastic strain. The specific creep is defined as the creep strain per unit stress. The creep compliance is defined as the creep strain plus elastic strain per unit stress, where the elastic strain is defined as the recoverable instantaneous deformation of a concrete specimen during the initial stage of loading.

1.2 Shrinkage and Creep Models of Concrete

Accuracy of shrinkage and creep models is important in the design of concrete structures. Any error in the prediction of creep and shrinkage may lead to excessive stress, cracking or large deflections and may cause losses in prestressed forces in a prestressed concrete elements. All these factors may lead finally to a structural failure.

Designers generally utilize one of the following two code models to estimate shrinkage and creep strain in concrete. The first model is the ACI 209[1, 2] recommended by the American Concrete Institute while the other model is the CEB 90[3, 4, 5] recommended by the Euro-international concrete committee. With the advent of computers and the availability of more test data from all around the world, new refined prediction models have been proposed by researchers to calculate shrinkage and creep. Three well-known models are: the B3 model,[6, 7] the GZ model,[8, 9] and the SAK model.[10] These three models vary in their level of complexity and are claimed by their authors to give as good or better prediction than the existing two code models. Hence this study will investigate the accuracy of these models for shrinkage and creep prediction and compare them with the existing code models.

1.3 Scope

In order to determine the accuracy of prediction for the five creep and shrinkage models mentioned in Section 1.2, predicted strain values from each model were compared with experimental data sets provided by the RILEM data bank.[11] The RILEM data bank contains a compilation of data around the world. As of 1999, around 512 creep experimental data sets and 419 shrinkage experimental data sets were available in this data bank. In this study, a total of 127 data sets (2200 data points) for creep and 82 data sets (1333 data points) for shrinkage were utilized. To compare the models, not all the experimental data sets were utilized in this evaluation, either because of incomplete information provided by the data sets or because some parameters of the experiments do not satisfy the limitations of the models.

In a number of papers[5, 6, 7, 8, 9, 10, 12, 13, 14] on creep and shrinkage, comparisons between experimental data and prediction methods have been presented by various researchers. Bazant et al.,[6, 7, 12] Gardner and Zhao,[8, 9] Sakata,[10] Muller and Hilsdorf, [5, 13] and McDonald[14] have used different statistical methods to analyze various creep and shrinkage models. In this study, seven different methods were utilized for the analysis of the models. They are the residual method,[14] the average and the standard deviation methods, the B3 coefficient of variation method,[6, 7] the CEB coefficient of variation method,[5, 13] the CEB mean square error method[5, 13] and the CEB mean deviation method.[5, 13] To analyze the models for their accuracy, different approaches were used for grouping creep and shrinkage data points. The predicted model values were grouped together and sorted out in different time ranges. Either two or six time range intervals were considered.

1.4 Objective

The main objective of this work is to evaluate five different design models utilized for predicting shrinkage and creep of concrete. The models under investigation will be evaluated for their accuracy, utilizing the RILEM experimental data bank. Seven different statistical methods will be used to evaluate the models. Some of these statistical methods were used by other researchers[5, 6, 7, 13, 14] to evaluate different shrinkage and creep models but none of the researchers has applied these statistical methods collectively in one study. Hence in this study, all these methods together were utilized to evaluate the models. For each statistical method, the two best performing models are identified and ranked as first and second. The model that ranks first or second for the highest number of statistical methods is considered to be the best performing model.

1.5 Thesis Outline

This thesis consists of five chapters. Chapter 1 gives an introduction on creep and shrinkage. A literature review on the five creep and shrinkage models utilized in this study is presented in Chapter 2. Chapter 3 describes various statistical methods used to analyze the models. The results of the analysis and its interpretations are presented in Chapter 4. Chapter 5 contains the conclusions and recommendations for future research.

1.6 References

1. Bazant, Z. P., "Mathematical Models for Creep and Shrinkage of Concrete," *Creep and Shrinkage in Concrete Structures*, p. 163-183, Edited by Z. P. Bazant and F. H. Wittmann, 1982, John Wiley & Sons Ltd.

2. ACI Committee 209-95, *Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures*, ACI Manual of Concrete Practice, Part 1, Materials and General Properties of Concrete, 1998.

3. Eurocode 2: Design of Concrete Structures - Part 1-1*: General Rules and Rules for Buildings*, March 1990.

4. Muller, H. S., *New Predication Models for Creep and Shrinkage of Concrete*, ACI Publication SP 135, p. 1-18, 1992.

5. CEB, Bulletin d' information, No. 199, *Evaluation of the Time Dependent Behavior of Concrete,* Summary Report on the Work of General Task Group 9, Prepared by H. S. Muller and H. K. Hillsdorf., September 1990.

6. Bazant, Z. P. and Baweja, S., "Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures - Model B3," *Material and Structures,* RILEM, Paris, Vol. 28, p. 357-365, 415-430, 488-495.

7. Bazant, Z. P. and Baweja, S., "Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures," Presented at the Adam Neville Symposium, Atlanta, Georgia, November 1997.

8. Gardner, N. J., and Zhao, J. W., "Design Provisions for Shrinkage and Creep of Concrete," Presented at the Adam Neville Symposium, Atlanta, Georgia, November 1997.

9. Gardner, N. J., and Zhao, J. W., "Creep and Shrinkage Revisited," *ACI Material Journal,* Vol. 90, May-June 1993, p. 236-246.

10. Sakata, K., "Prediction of Concrete Creep and Shrinkage," *Creep and Shrinkage of Concrete*, Proceedings of the Fifth International RILEM Symposium, Barcelona, Spain, p. 649-654, 1993.

11. RILEM Databank provided by Dr. Harold S. Muller, Universitat Karlsruhe(TH), Institute fur Massivbau und Baustofftechnologie, Abteilung Baustofftechnologie, Postfach, D-76128 Karlsruhe, Germany.

12. Bazant, Z. P. and Panula, L., "Creep and Shrinkage Characterization for Analyzing Prestressed Concrete Structures," *PCI Journal,* Vol. 25, No. 3, p. 86-122, May-June 1980.

13. Muller, H. S. and Hilsdorf, H. K., "Comparison of Prediction Methods for Creep Coefficients of Structural Concrete with Experimental Data," *Fundamental Research on Creep and Shrinkage of Concrete*, Papers presented at a conference held at the Swiss Federal Institute of Technology in Lausanne, Edited by F. H. Wittman, p. 269-278, September 1980.

14. McDonald, D. B., *Selected Topics on Drying Shrinkage, Wetting Expansion and Creep of Concrete*, Thesis submitted for the Degree of Doctor of Philosophy, Vol. I, Department of Civil and Mining Engineering, University of Sydney, May 1990.

Chapter 2

Review of Shrinkage and Creep Models

2.1 Introduction

Shrinkage and creep are two important factors affecting long-term behavior of existing concrete structures. The deflection due to these long-term time dependent effects can be significantly larger than the short-term elastic deflection. Consequently an accurate prediction model for shrinkage and creep is important to ensure safe and durable concrete structures.

Two types of formulations have been used when modeling the creep behavior of concrete. These are: the product model and the summation model.[1] The product model, called the aging creep model, predicts creep as a product of two functions. One function describes the effect of age at loading while the other function describes the development of creep with time under constant load. In the summation model, which is called the rate of flow model, the creep is calculated by separating delayed elasticity and flow. All models investigated in this study, the ACI 209,[2, 3] the CEB 90,[1, 4, 5] the B3,[6] the GZ[7, 8] and the SAK models[9] were classified as product models. The equations describing each model are given in Appendix I.1 through I.5 and a review of each model will be given in the next sections.

2.2 The ACI 209 Code Model

The ACI 209 model[2, 3] is the design code model used in the United States for predicting shrinkage and creep of concrete structures. This model was introduced for the first time in 1970. Prior to 1970, various methods were proposed by different researchers and a review of these methods was presented by Branson[10] in 1977. Some of these methods are summarized below.

In 1936, Shank[11] provided a simple power equation for creep up to one year. But the Shank method overestimates creep strain. This was followed by a hyperbolic equation presented by Ross[12] in 1937 to predict creep and shrinkage. The Ross equation in general underestimates long term creep. In 1943, Schorer[13] presented an equation for estimating ultimate shrinkage strain of hardened concrete that mostly underestimates shrinkage strain. In 1953, based on a study conducted by the Bureau of Reclamation[14] on concrete dams, a logarithmic equation was developed for creep. A logarithmic equation assumes that creep and shrinkage continue indefinitely and the drawback in this type of equation is that it does not provide an ultimate value. In 1959, Jones, Hirsch and Stephenson[15] proposed a procedure to predict specific creep and shrinkage of lightweight concrete that refers to standard curves. Correction curves for the effect of relative humidity, cement content, water-to-cement ratio and minimum dimension were also given. In 1962, Ulitskii[10] gave an exponential equation for calculating the creep coefficient and shrinkage strain. Exponential equations in general assume limiting values for creep and shrinkage, but they underestimate long-term values. In 1969, Neville, Ward, and Kwei[16] presented a simplified expression for total creep, in terms of basic creep plus drying creep. In this expression, both basic and drying creep are influenced by applied stress, while the drying creep is given as function of shrinkage.

In 1970, Branson et al.[2, 3] presented a set of standard equations and conditions to predict shrinkage and creep. For nonstandard conditions correction factors in the form of equations, tables and curves were given. The current ACI 209 model[3] is based on the works by Branson et al. In this model, expressions similar to the hyperbolic equation of Ross [12] were given for the rates of shrinkage and creep as functions of time. The creep coefficient is used to calculate creep strain and the model accounts for moist and steam cured concrete. Correction factors for the effects of humidity, slump, air content, cement content, fine aggregate percentage, size and shape of specimen and age of loading are utilized in this model. The ACI 209 model can be applied for type I and type III portland cements with relative humidity ranging between 40% and 100%.

2.3 The B3 Model

The B3 model was proposed by Bazant and Baweja[6] in 1997. An earlier version of this model proposed in 1978 was called the BP model[17] which was then modified in 1991 and called the BP-KX model.[18] The BP-KX model gave equations to predict shrinkage strain, basic creep, drying creep, temperature effect on basic creep, temperature effect on drying creep and effects of cyclic stress and cyclic humidity. The BP-KX model comes in two versions, expanded and short. The expanded version is recommended for structures with high sensitivity to the effects of creep and shrinkage, while the simplified

BP-KX model[19] was presented for code type recommendations. A short form of the BP-KX model[20] was presented for predicting creep compliance.

The B3 model used in this study is a simpler version of the expanded BP-KX model. In the B3 model, the shrinkage strain is calculated as the product of the ultimate shrinkage strain and the equations to incorporate factors to take into account time and humidity effects. The ultimate shrinkage strain is given as function of the mean 28-day concrete compressive strength and water content. Correction factors for type of cement and method of curing on ultimate shrinkage strain is given.

The creep strain is predicted as creep compliance. The creep compliance is expressed as the sum of instantaneous strain due to unit stress, basic creep and drying creep. The basic creep is given as a function of mix design of a particular concrete. Drying creep is given as function of the ultimate shrinkage strain, the mean 28-day concrete strength, age, and the relative humidity. In this model drying creep of a very thick specimen is considered to be negligible within the normal lifetime span of a structure. This model provides a different set of equations to consider the effect of elevated temperature on basic creep strain.

The B3 model is restricted to concretes with mean compressive strengths ranging from 2500 psi to 10,000 psi, humidity ranging between 40% and 100%, water-cement ratios of 0.3 to 0.85, cement contents 10 lb/ft^3 to 45 lb/ft^3, and aggregate-to-cement ratios of 2.5 to 13.5. If the model parameters are calibrated by tests, then the model can be applied outside these limits.

2.4 The CEB 90 Code Model

The CEB 90[1, 4, 5] shrinkage and creep model is the recommendation of the CEB-FIP Model Code 1990 (Euro-International Concrete Committee and International Federation for Prestressing). Earlier models recommended by the CEB-FIP Model Code are: the CEB-FIP – 1970[1, 5, 21] model and the CEB-FIP – 1978[1, 5, 21] model. The CEB-FIP – 1970 model, a product model, uses multiplication of correction factors from graphs to account for different mix properties and environmental conditions. The CEB-FIP – 1978 model, a summation model, requires summation of all correction factors using graphs.

In the CEB 90[4, 5] model, which is a product model, the shrinkage strain is expressed as the product of two functions. One function for the notional shrinkage coefficient and the other function to describe the development of shrinkage with time. The parameter concrete strength is introduced into the shrinkage prediction as a measure of the effect of concrete composition. A correction factor for the effect of cement type and relative humidity on shrinkage strain is given. A different set of equations is provided to consider the effect of elevated temperatures on shrinkage.

The creep strain is calculated using the creep coefficient, which is calculated as the product of the notional creep coefficient and another coefficient describing the development of creep with time after loading. An expression is given for the notional creep coefficient to model both the effect of concrete strength and the effect of age at loading. The development of creep with time is given as a function of the relative humidity and the member size. The effect of elevated temperature on steady state creep (i.e. exposure of structural member to the temperature prior to drying) and transient creep (i.e. exposure of structural member to the temperature after loading) are given in the model.

The CEB 90 model is valid for concrete structures having mean 28-day compressive strength ranging from 2900 psi to 13,000 psi and relative humidity of 40% to 100% at mean temperatures from 5 °C to 30 °C.

2.5 The GZ Model

This model was proposed by N. J. Gardner.[7, 8] In this model, equations to calculate the modulus of elasticity, shrinkage, and creep coefficient are given as functions of the concrete compressive strength. Shrinkage strain is expressed as the product of the ultimate shrinkage strain and correction factors for type of cement, humidity, time of shrinkage duration, and volume-to-surface area ratio. The ultimate shrinkage strain is a function of the mean concrete compressive strength at 28-days and at the beginning of shrinkage duration.

The creep strain is calculated using the creep coefficient, which is dependent on concrete compressive strength at 28-days, the mean concrete compressive strength at loading, the humidity, and volume-to-surface area ratio. A correction factor for drying before loading is also included in the model. If the beginning of shrinkage and the age of loading are the same, the correction term for drying before loading is set to one. The limits of validity for this model are: relative humidity of 40% to 100%; mean concrete compressive strength between 2900 psi and 10,000 psi; temperature range 15 °C to 30 °C; age of loading greater than or equal to 2 days.

2.6 The SAK Model

The SAK model was proposed by K. Sakata[9] and is the recommended method of the Japan Society of Civil Engineers. To predict shrinkage strain, two equations were utilized. One is used to calculate the ultimate shrinkage, while the other is used to calculate the total shrinkage. Ultimate shrinkage is given as a function of relative humidity, water content, and effective thickness of the member.

To calculate the creep strain, the specific creep is predicted as a function of the basic creep plus drying creep. The basic creep depends on the cement content, water content, and the age of loading whereas drying creep is dependent on the cement content, water content, volume-to-surface area ratio, the relative humidity, and age of concrete at the beginning of the shrinkage.

The SAK model is valid for concrete structures exposed to relative humidity of 40% to 80%, with cement content of 16 to 31 lb/ft^3, and water-to-cement ratio of 0.4 to 0.6. The age of concrete at loading or age of concrete at the start of shrinkage duration should be more than 7 days.

2.7 Summary

The complexity of each shrinkage and creep model varies by including different input parameters and specifying different ranges of applicablity. The limitations of the models input parameters are given in Sections 2.2 to 2.6 and are summarized in Table 2.1. Due to the limitations in the ranges of applicability of the models, not all experimental data sets from the RILEM data bank[22] were utilized in this evaluation. Considering these limitations, data sets were selected from the data bank that fit all model requirements. The selection criteria was based on four distinct input parameters: the mean 28-day concrete compressive strength, relative humidity, type of cement and age of concrete at loading or the age of concrete at the beginning of shrinkage duration. The selection criteria for data sets utilized in this work for creep and shrinkage are summarized in Table 2.2.

The models differ considerably in the number of input parameters required to predict creep and shrinkage. The input parameters required by each of the five models are summarized in Table 2.3. The common factors that are required by all models are the applied stress, the age of concrete at loading, the age of concrete at the beginning of shrinkage, the type of cement, the effective thickness of the member, and the relative humidity. The B3, the CEB 90 and the GZ models require either the specified 28-day concrete compressive strength or the mean 28-day concrete compressive strength, whereas the ACI 209 model requires the mean 28-day concrete compressive strength. In addition, concrete mix compositions are required for the B3 and the SAK models. Equations describing all five models and examples on calculating shrinkage and creep utilizing all models are given in Appendix I and II.

Table 2.1: Limitations of Models

Category	Models				
	ACI 209	B3	CEB 90	GZ	SAK
f_{cm} (psi)	–	2500-10000	2900-13000	2900-10000	–
a/c	–	2.5-13.5	–	–	–
c (lb/ft^3)	–	10-45	–	–	16-31
w/c	–	0.35-0.85	–	0-0.6	0.4-0.6
H (%)	40-100	40-100	40-100	40-100	40-80
Type of cement	I or III	I, II or III	R, SL or RS	I, II or III	I or III
t_o or t_s (moist cured)	≥ 7 days	$t_s \le t_o$	–	≥ 2 days	≥ 7 days
t_o or t_s (steam cured)	≥ 1-3 days	$t_s \le t_o$	–	≥ 2 days	≥ 7 days

Table 2.2: Criteria for Selection of Data

Category	Creep Compliance	Shrinkage Strain
f_{cm} (psi)	2900-10000	2900-10000
H (%)	40-80	40-80
Type of cement	I, R, II, SL, III, RS	I, R, II, SL, III, RS
t_o or t_s	$t_o \ge 7$ days	$t_s \ge 7$ days

f_{cm} = Mean 28-day concrete compressive strength
a/c = Aggregate-to-cement ratio
c = Cement content
w/c = Water-to-cement ratio
H = Relative humidity
I = North American normal Portland cement
II = North American moderate sulfate resistance cement
III = North American high early strength cement
R = European rapid hardening cement (assumed equivalent to type I cement)
SL = European slow hardening cement (assumed equivalent to type II cement)
RS =European rapid hardening high strength cement (assumed equivalent to type III cement)
t_o = Age of concrete at loading
t_s = Age of concrete at the beginning of shrinkage

Table 2.3: Factors Required for Models

Category	Models				
	ACI 209	B3	CEB 90	GZ	SAK
a/c	NR	R	NR	NR	NR
f_{cm} or $f'_{c\,(28)}$	R	R	R	R	NR
c	NR	R	NR	NR	R
H	R	R	R	R	R
w	NR	R	NR	NR	R
w/c	NR	R	NR	NR	NR
t_o	R	R	R	R	R
t_s	R	R	R	R	R
Type of cement	R	R	R	R	R
V/S or A/u	R	R	R	R	R
σ	R	R	R	R	R

R = Required

NR = Not required

A/u = Area of member to its perimeter ratio

a/c = Aggregate-to-cement ratio

c = Cement content

$f_{cm} = f'_{c\,(28)}$ = Mean 28-day concrete compressive strength

H = Relative humidity

t_o = Age of concrete at loading

t_s = Age of concrete at the beginning of shrinkage

V/S = Volume-to-surface area ratio

w/c = Water-to-cement ratio

σ = Applied stress

2.7 References

1. Muller, H. S., "New Predication Models for Creep and Shrinkage of Concrete," *ACI Publication* SP 135, p. 1-18, 1992.

2. Branson, D. E. and Christianson, M. L., "Time-dependent Concrete Properties Related to Design Strength and Elastic Properties, Creep and Shrinkage," ACI, SP 27-13, *Designing for Creep, Shrinkage and Temperature*, p. 257-277, 1971.

3. ACI Committee 209-95, "Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures," ACI Manual of Concrete Practice, Part 1, *Materials and General Properties of Concrete*, 1998.

4. Eurocode 2: Design of Concrete Structures - Part 1-1: *General Rules and Rules for Buildings*, March 1990.

5. CEB, Bulletin d' information, No. 199, *Evaluation of the Time Dependent Behavior of Concrete*, Summary Report on the Work of General Task Group 9, Prepared by H. S. Muller and H. K. Hillsdorf., September 1990.

6. Bazant, Z. P. and Baweja, S., "*Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures*," Presented at the Adam Neville Symposium, Atlanta, Georgia, November 1997.

7. Gardner, N. J., "*Design Provisions for Shrinkage and Creep of Concrete*," Presented at the Adam Neville Symposium, Atlanta, Georgia, November 1997.

8. Gardner, N. J., and Zhao, J. W., 1993, "Creep and Shrinkage Revisited," *ACI Material Journal*, Vol. 90, p. 236-246, May-June 1993.

9. Sakata, K., "Prediction of Concrete Creep and Shrinkage," *Creep and Shrinkage of Concrete,* Proceedings of the Fifth International RILEM Symposium, Barcelona, Spain, p. 649-654, September 6-9, 1993.

10. Branson, D. E., "*Deformation of Concrete Structures,*" 1977, McGraw-Hill Inc.

11. Shank, J. R., "The Mechanics of Plastic Flow of Concrete," Proceedings 32, *American Concrete Institute,* p. 149-180, 1936.

12. Ross, A. D., "Concrete Creep Data," *The Structural Engineer,* Vol. 15, p. 314-326, August 1937.

13. Schorer, H., "Prestressed Concrete Design Principles and Reinforcing Units," *ACI Journal,* Proceedings 39, p. 493-528, July 1943.

14. Bureau of Reclamation, *A 10-year Study of Creep Properties of Concrete,* U.S. Bureau of Reclamation Report, SP-38, Denver, Colo., 1953.

15. Jones, T. R., Hirsch, T. J., and Stephenson, H. K., *The Physical Properties of Structural Quality Lightweight Aggregate Concrete,* Texas Transportation Institute, Texas A & M University, Texas, August 1959.

16. Neville, A. M., Ward, M. A., and Kwei, G. G., "Basic and Drying Creep of Concrete," *Materials and Structures,* Vol. 2, p. 117-124, 1969.

17. Bazant, Z. P. and Panula, L., "Practical Prediction of Time Dependent Deformation of Concrete," Parts I and VI, *Materials and Structures,* 1978, Parts V and VI, 1979.

18. Bazant, Z. P. and Kim, Joong-Koo., "Improved Prediction Model for Time Dependent Deformations of Concrete, Part 1 - Shrinkage," *Materials and*

Structures, Vol. 24, p. 327-345, 1991, Part 2 - Basic Creep, Vol. 24, p. 409-442, 1991, Part 3 - Creep at Drying, Vol. 25, p. 21-28, 1992, Part 4 - Temperature Effects, Vol. 25, p. 84-94, 1992, Part 5 - Cyclic Load and Cyclic Humidity, Vol. 25, p. 163-169, 1992.

19. Bazant, Z. P., Panula, L., Kim, Joong-Koo., and Xi, Y., "Improved Prediction Model for Time Dependent Deformation of Concrete, Part VI - Simplified Code-type Formulation," *Materials and Structures,* Vol. 25, p. 219-223, 1992.

20. Bazant, Z. P., Xi, Y., and Baweja, S., "Improved Prediction Model for Time Dependent Deformation of Concrete, Part VII - Short Form of BP-KX Model, Statistics and Extrapolation of Short-Time Data," *Materials and Structures,* Vol. 26, p. 567-574, 1993.

21. Smerda, Zdenek., and Kristek, Vladimir., "Creep and Shrinkage of Concrete Elements and Structures," *Developments in Civil Engineering,* Vol. 21, 1988, Elsevier Science Publishing Company, Inc.

22. RILEM Databank provided by Dr. Harold S. Muller, Universitat Karlsruhe(TH), Institute fur Massivbau und Baustofftechnologie, Abteilung Baustofftechnologie, Postfach, D-76128 Karlsruhe, Germany.

Chapter 3

Methods Used to Analyze the Models

3.1 Introduction

Real structures under service conditions are always subjected to variation of loads and fluctuating environmental conditions. Hence no shrinkage or creep model can give accurate results unless short term test data are available on the concrete used for that particular structure. In order to obtain some insight into the reliability of various prediction methods, predicted model values are compared with the RILEM experimental data bank and evaluated utilizing various statistical methods.

In the RILEM data bank, the measured creep or shrinkage data points in a single data set are not equally spaced in the logarithmic scale of creep duration or shrinkage duration. Hence in previous studies[1, 2, 3, 4, 5] on evaluating shrinkage and creep models, different methods of grouping test data were used. In the B3 coefficient of variation method,[2, 3] for each data set weights are assigned to the data points based on the decade in which they fall and the number of data points in that particular decade. In the CEB coefficient of variation method,[4, 5] individual test data presented in logarithmic time scale are hand smoothed for a best curve fit and the values are then analyzed at constant intervals.

In this study, a different approach on grouping shrinkage and creep data points is utilized. Model values for all data sets from the data bank are first calculated. The predicted model values were then grouped together and sorted out in different time ranges. Data are grouped into either two or six time range intervals. When two time ranges are used, a short (0-1000 days) and a long (0-7000 days) time interval are utilized. When the data are grouped into six time ranges, intervals of 0-10 days, 10-100 days, 100 days-1 year, 1-2 years, 2-3 years and above 3 years are utilized.

3.2 The Residual Method

The residual method was utilized in a previous work by McDonald,[1] in which the residual values are obtained by subtracting experimental strain or compliance values from predicted model values. The calculated positive and negative residuals are plotted on either sides of the y-axis versus time. A positive residual indicates that a model is overestimating creep or shrinkage strain, whereas a negative residual means that a model is underestimating creep or shrinkage strain. If a model predicts accurately for a particular data set then the residual will be on the zero horizontal line or very close to it.

In this study, the residuals and the error percentage of the predicted values are calculated and plotted versus time. Error percentage is calculated using the following equation:

$$\text{Error percentage} = \frac{\text{Residuals x 100}}{\text{Experimental values}} \qquad (3\text{-}1)$$

The error percentage values of a given model are calculated and plotted versus time for long term periods only. The error percentage is a reliable measure for model values calculated for the prolonged time duration. However for the short time period, the error percentage may be misleading because experimental values are very small for initial periods resulting in high error percentages for small measurements. In the residual method the residuals are calculated and analyzed in two time ranges, short and long term duration. For the short term duration, a total of 2083 experimental creep compliance values and 1209 experimental shrinkage strain values are utilized. For the long term duration a total of 2200 experimental creep compliance values and 1333 experimental shrinkage strain values are utilized.

For further evaluation of the residuals, the number of residual points in various residual ranges are analyzed. For shrinkage strain, the number of residuals in two different ranges of 0 to ±100 microstrain and over ±100 microstrain are calculated and compared. For creep compliance, two different ranges of 0 to ± 0.23 microstrain/psi and over ± 0.23 microstrain/psi were utilized. In this study, lower residual values for shrinkage strain are defined as being in the range of 0 to ± 100 microstrain and for creep compliance defined in the range of 0 to ±0.23 microstrain/psi. This lower range is ±25% of the total distribution of shrinkage strain residuals and creep compliance residuals of all five models.

3.3 The Average and Standard Deviation Methods

The average of residuals is the mean of all data points considered in a particular time range. The standard deviation of residuals is a measure of how widely the residuals deviate from the average value. The following equations were utilized to calculate the average and standard deviation.

$$A_j = \frac{\sum_{i=i}^{n} X_i}{n} \tag{3-2}$$

$$S_j = \sqrt{\frac{n \sum_{i=1}^{n} (X_i^2) - (\sum_{i=1}^{n} X_i)^2}{n(n-1)}} \tag{3-3}$$

A_j = Average of residuals or compliance for fixed time j

n = Total number of values considered at a fixed time

S_j = Standard deviation of residuals or compliance for fixed time j

X_i = Residual or compliance value of the i^{th} data point in a fixed time j

In this study, the average and standard deviation of creep compliance were calculated utilizing the short and long term duration. The average and standard deviation of shrinkage and creep residuals were calculated utilizing both two time intervals (i.e. short and long term duration) and six time intervals.

3.4 The B3 Coefficient of Variation (ω_{B3}%) Method

The B3 coefficient of variation method was suggested by Bazant and Baweja.[2, 3] The coefficient of variation ϖ is calculated for individual data sets as shown in equation 3-4, 3-5 and 3-6. The overall coefficient of variation (ω_{B3}) for all data sets is then given as a percentage as calculated by equation 3-7. For a single data set, the data points in each decade of the logarithmic scale of load duration or shrinkage duration are considered as one group, and each data point in that group is assigned equal weight. Weight is assigned to a data point based on the decade in which it falls and the number of data points in that particular decade. A decade of creep or shrinkage duration is defined as follows:

0-10 days = Decade one

10-100 days = Decade two

100-1000 days = Decade three

1000-10000 days = Decade four

$$\varpi_j = \frac{1}{\bar{J}_j}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\omega_{ij}\,\Delta_{ij})^2} \qquad (3\text{-}4)$$

$$\bar{J}_j = \frac{1}{n_w}\sum_{i=1}^{n}(\omega_{ij}\,J_{ij}) \qquad (3\text{-}5)$$

$$\omega_{ij} = \frac{n}{n_d\,n_k} \qquad (3\text{-}6)$$

$$\omega_{B3} = \sqrt{\frac{1}{N} \sum_{j=1}^{N} \varpi_j^2} \qquad (3\text{-}7)$$

n = Number of data points in data set number j

n_w = Sum of the weights of all data points in a data set

n_k = Number of data points in the k^{th} decade

n_d = Number of decades on the logarithmic scale spanned by measured data in data set number j

N = Number of data sets in the data bank

J_{ij} = Measured value of the compliance function or shrinkage strain for the i^{th} data point in data set number j

Δ_{ij} = Deviation of the compliance function or shrinkage strain value given by the model from the measured value for the i^{th} data point in data set number j

ω_{ij} = Weight assigned to the i^{th} data point in data set number j

ϖ_j = Coefficient of variation for data set number j

ω_{B3} = Overall coefficient of variation of the deviations of the model from the measured values for all the data sets in the data bank

In this study, the coefficient of variation for creep compliance or shrinkage strain was calculated for each individual data set using equations 3-4, 3-5, and 3-6. The overall coefficient of variation for all the data sets is then calculated using equation 3-7. An example of the procedure utilized in this method is given in Appendix III.

3.5 The CEB Coefficient of Variation (V_{CEB} %) Method

This method was suggested by Muller and Hilsdorf[4,5] and was utilized by the CEB to evaluate the models. The CEB coefficient of variation method is similar to that of the B3 coefficient of variation (ω_{B3}) method except that for the B3 method, weights are assigned to data points, whereas for the CEB method, individual experimental data sets presented on a logarithmic time scale are hand smoothed to a curve and then the coefficient of variation is calculated using equally spaced data points in logarithmic time from the smoothed curve. To evaluate the accuracy of a particular prediction method on the basis of N experimental data sets the mean coefficient of variation, V_{CEB} is calculated from the following equations:

$$Y_i = \frac{\sum_{j=1}^{n} Y_{ij}}{n} \tag{3-8}$$

$$S_i = \sqrt{\frac{1}{n-1} \sum_{j=1}^{n} (\Delta Y_{ij})^2} \tag{3-9}$$

$$V_i = \frac{S_i}{Y_i} \times 100 \tag{3-10}$$

$$V_{CEB} = \sqrt{\frac{1}{N} \left(\sum_{i=1}^{N} V_i^2\right)} \tag{3-11}$$

n = Number of differences (data points) taken for each experiment

N = Total number of data sets

S_i = Standard error determined from ΔY_{ij} for experiment i

V_i = Coefficient of variation of experiment i

$\mathbf{V_{CEB}}$ = Mean coefficient of variation

Y_i = Mean creep compliance or shrinkage strain of experiment i

Y_{ij} = Observed creep compliance or shrinkage strain at time j of experiment i

ΔY_{ij} = Difference between observed shrinkage strain or compliance and predicted shrinkage strain or compliance at time j of experiment i, with the differences being taken at constant intervals along the log time axis

In this study, the coefficient of variation V_i for shrinkage strain and creep compliance is calculated in six different time ranges for each duration using equation 3-10 of 0-10 days, 10-100 days, 100 days-1 year, 1-2 years, 2-3 years and above 3 years, and their mean coefficient of variation $\mathbf{V_{CEB}}$ is then calculated using equation 3-11.

3.6 The CEB Mean Square Error (F_{CEB} %) method

The mean square error ($\mathbf{F_{CEB}}$) suggested by Muller and Hilsdorf[4,5] is an indication of the overall error of predicted values. The value $\mathbf{F_i}$ is calculated for each data point as smoothed time creep duration or shrinkage duration then a mean square error, $\mathbf{F_{CEB}}$ is calculated for each prediction method. The following equations are used to describe this method:

$$\mathbf{f_j} = \frac{(\text{Cal } X_{ij} - \text{Obs } X_{ij}) \times 100}{(\text{Obs } X_{ij})} \tag{3-12}$$

$$F_i = \sqrt{\frac{1}{n-1} \sum_{j=1}^{n} f_j^2} \tag{3-13}$$

$$F_{CEB} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} F_i^2} \tag{3-14}$$

Cal X_{ij} = Predicted shrinkage strain or creep compliance of time j of experiment i

Obs X_{ij} = Experimental shrinkage strain or creep compliance of time j of experiment i

f_j = Percent difference between calculated and observed data point j

F_{CEB} = Mean square error

n = Total number of values j of experiment i considered at a fixed time

N = Total number of data sets

In this study, the square error F_i is calculated for six different time ranges of 0-10 days, 10-100 days, 100 days-1 year, 1-2 years, 2-3 years and above 3 years using equations 3-12 and 3-13 and their mean square error F_{CEB} is calculated from these values using equation 3-14.

3.7 The CEB Mean Deviation (M_{CEB}) method

The CEB mean deviation method also suggested by Muller and Hilsdorf[4.5] is a method to indicate systematic overestimation or underestimation of a given model. The value M_i is calculated for a fixed time of creep duration or shrinkage duration then the mean deviation M_{CEB} is calculated. The following equations describe the procedure to calculate M_{CEB}:

$$M_i = \frac{1}{n} \sum_{j=1}^{n} \frac{\text{Cal } X_{ij}}{\text{Obs } X_{ij}} \tag{3-15}$$

$$M_{CEB} = \frac{\sum_{i=1}^{N} M_i}{N} \tag{3-16}$$

Cal X_{ij} = Predicted shrinkage strain or creep compliance of time j of experiment i

Obs X_{ij} = Experimental shrinkage strain or creep compliance of time j of experiment i

M_{CEB} = Mean deviation

n = Total number of values j of experiment i considered at a fixed time

N = Total number of data sets

In this study, the deviation M_i is calculated for six different time ranges of 0-10 days, 10-100 days, 100 days-1 year, 1-2 years, 2-3 years and above 3 years using equation 3-15 and their mean deviation M_{CEB} is then calculated using equation 3-16.

3.4 References

1. McDonald, D. B., *Selected Topics on Drying Shrinkage, Wetting Expansion and Creep of Concrete,* Thesis submitted for the Degree of Doctor of Philosophy, Vol. I, Department of Civil and Mining Engineering, University of Sydney, May 1990.

2. Bazant, Z.P. and Baweja, S., "Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures - Model B3," *Material and Structures,* RILEM, Paris, Vol. 28, p. 357-365, 415-430, 488-495.

3. Bazant, Z.P. and Baweja, S., "Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures," Presented at the Adam Neville Symposium, Atlanta, Georgia, November 1997.

4. Muller H.S., and Hilsdorf H.K., "Comparison of Prediction Methods for Creep Coefficients of Structural Concrete with Experimental Data," *Fundamental Research on Creep and Shrinkage of Concrete*, Papers presented at a conference held at the Swiss Federal Institute of Technology in Lausanne, Edited by Wittman F.H., p. 269-278, September 1980.

5. CEB, Bulletin d' information, No. 199, *Evaluation of the Time Dependent Behavior of Concrete,* Summary Report on the Work of General Task Group 9, Prepared by H. S. Muller and H. K. Hillsdorf., September 1990.

Chapter 4

Results of the Study

4.1 Introduction

The shrinkage and creep prediction models are evaluated for their accuracy using the experimental RILEM data bank. Various statistical methods were applied to characterize the accuracy of the values predicted by the models. Results of all the statistical methods were summarized and rated. The first two best performing models are identified and ranked as first and second for a given statistical method. The model that ranks first or second for most of the statistical methods is considered to be the best performing model.

4.2 Analysis of Shrinkage Strain

The shrinkage strain values of all models were calculated for all the experimental data points selected from the RILEM data bank. The residuals and the error percentage were then calculated and plotted versus time. The residual points were grouped into various ranges so that the total number in each range could be compared between the five models. The average and standard deviation of the residuals were also calculated. The B3 coefficient of variation (ω_{B3}), the CEB coefficient of variation ($\mathbf{V}_{CEB}$), the CEB mean square error ($\mathbf{F}_{CEB}$) and the CEB mean deviation ($\mathbf{M}_{CEB}$) of the model's predicted strain values were calculated and assessed for model accuracy.

4.2.1 Analysis of Shrinkage Strain Residuals

Figures 4.1 to 4.10 show the residuals of shrinkage strain for all five models using the short and long term duration groups. Residuals in the positive range indicate that the corresponding model values overestimated the data values, whereas the negative residuals indicates that the corresponding model values underestimated the data values. Table 4.1 summarizes the distribution of residuals for both shrinkage and creep.

Figures 4.1 and 4.2 show the shrinkage strain residuals for the ACI 209 model. It can be observed from the figures and Table 4.1 that the residuals are mostly distributed on the positive side. The residuals varied from +627 to –330 microstrain for this model.

Figures 4.3 and 4.4 show the shrinkage strain residuals calculated for the B3 model. It can be observed from the figures and Table 4.1 that the residuals are mostly distributed on the negative side. Figure 4.4 show that the model underestimate most of the data points. The residuals of the B3 model varied from +361 to –331 microstrain.

Figures 4.5 and 4.6 show the shrinkage strain residuals for the CEB 90 model. It can be observed from the figures and Table 4.1 that the shrinkage strain residuals of the CEB 90 model are mostly distributed on the negative side. The residuals of the CEB 90 model varied from +352 to –391 microstrain.

Figures 4.7 and 4.8 show the shrinkage strain residuals of the GZ model. It can be observed from Figure 4.8 and Table 4.1 that the residuals were well balanced on the positive and negative range compared to other four models in the long term duration. The residuals varied from +263 to –407 microstrain for the GZ model.

Figures 4.9 and 4.10 show the residuals of the SAK model. It can be observed from the figures and Table 4.1 that the SAK model overestimates most of the data points with large residual values. The residual values varied from +841 to −192 microstrain for this model.

The error percentage of the predicted model values calculated using equation 3-1 for all five models are given in Figures 4.11 through 4.15. It can be observed from these figures that the error percentage for all five models, for duration of 0-7000 days, varied between +1500% to −100%. The error percentage for duration between 10-7000 days varied from +750% to −65%. High error percentages were observed for the first ten days due to the low shrinkage values observed in the experimental data.

Table 4.1 gives the distribution of number of residual data points in the positive (overestimated) and negative (underestimated) range for each model. Figures 4.16 and 4.17 and Table 4.2 show the result of analysis of shrinkage strain residuals in various ranges. A residual range of 0 to ±100 microstrain is considered as a lower range for shrinkage strain. Residuals in this range are plotted by the white bar in Figures 4.16 and 4.17.

The results from Table 4.1 show that the ACI 209 model, overestimates the data point values in approximately 62% of the cases and underestimates them in approximately 38% of the cases over the short time duration. It can be further observed that the residual distribution for the 0-7000 day duration indicates the model overestimates by 60% of the data which is different from the model performance for the period of 0-1000 days.

When analyzing the shrinkage strain residuals for the ACI 209 from Table 4.2 and Figures 4.16 and 4.17 it is evident that for the long time duration only 57% of the total number of residuals lie in the lower range of 0 to ±100 microstrain. For the remaining residuals outside the range of 0 tc ±100 microstrain, 29% of the total residual points were in the range between +100 and + 627 microstrain while only 14% of the total residual points were in the residual range between −100 and −330 microstrain.

Table 4.1 indicates that, for the short and long time duration observations of shrinkage, the B3 model has 36% in the positive range and 64% in the negative range. Table 4.2 and Figures 4.16 and 4.17 show that, for the long time duration, approximately 67% of the total number of residuals were in the lower range of 0 to ±100 microstrain. About 8% of the total number of residual points were in the positive range between +100 to +361 microstrain, whereas 25% of the total number of residual points were distributed in the negative range between −100 and −331 microstrain.

For the CEB 90 model, Table 4.1 show that the model overestimates approximately 40% and underestimates approximately 60% of the experimental data point values in the short time duration. For long time duration, the model overestimates and underestimates 39% and 61% of the data point values respectively. It can be observed from the Table 4.2 and Figures 4.16 and 4.17 that for the long time duration estimates approximately 61% of the total number of residuals were in the lower range of 0 to ±100 microstrain. Only 7% greatly overestimated the data with residual values varying from +100 to +352 microstrain, whereas the remaining 32% of the residuals had large negative values between −100 and −391microstrain.

Table 4.1 shows that the GZ model overestimates the data point values in approximately 41% of the cases and underestimates them in approximately 59% over the short time duration. For the long time duration the model overestimates and underestimates by 43% and 57% of the data respectively. Table 4.2 and Figures 4.16 and 4.17 show that approximately 62% of the total number of residuals is distributed in the lower range of 0 to ±100 microstrain for the long time duration. Also the model overestimated approximately 13% of the data with residual values between +100 and +263 microstrain and underestimated 25% with residual values between −100 and −407 microstrain.

For the SAK model, Table 4.1 show that the model overestimates 93% and 94% of the total number of shrinkage data points for the short and long time duration respectively. It can be observed from the Table 4.2 and Figures 4.16 and 4.17 that approximately 22% of the total number of residuals were in the lower range of 0 to ±100 microstrain for long time duration. Also the model overestimates 76% of the data with residual values between +100 and +841 microstrain and underestimated 2% with residual values between −100 and −192 microstrain.

In summary, the ACI 209 and the SAK models overestimate most of the data points whereas the B3, CEB 90 and the GZ models underestimate most of the data points. The residuals of the GZ model were well distributed on the positive and negative compared to the other four models, whereas the B3 model has high number of residuals in the lower range of 0 to ±100 microstrain.

4.2.2 Statistical Analysis of Shrinkage Strain

In this section the results of the average and standard deviation of residuals, the B3 coefficient of variation, the CEB coefficient of variation, the CEB mean square error and the CEB mean deviation of the shrinkage strain are analyzed.

The average of all positive and negative shrinkage strain residuals for two and six time ranges of a given model are calculated using equation 3-2 and given in Table 4.3. Figure 4.18 compares the mean average of residuals when residuals are grouped into the two and six time range intervals. It can be observed from Table 4.3 that the results of the ACI 209 model for the six time intervals slightly underestimates in the range of 0-10 days and above 3 years, whereas all other ranges were overestimated.

The best result is obtained by the B3 model for the two time ranges and by the GZ model for the six time ranges giving the lowest mean average of residuals. From Table 4.3 it can be observed that the B3 model underestimates most of the data points above 100 days (i.e. negative average of residuals), whereas the GZ model underestimates most of the data points in all time intervals except above 1100 days. The CEB 90 model gives a high negative average of residuals for both the two and six time interval groupings. One exception is the residual average for 0-10 days for the six time interval groupings. The SAK model gives the highest positive average of residuals among all models.

The standard deviation of all shrinkage strain residuals in both the two and six time range interval groupings for each model was calculated using equation 3-3 and summarized in Table 4.4. The results are also plotted in Figure 4.19. The B3 model has the lowest mean standard deviation of residuals for both the two and six time interval groupings followed by the GZ model, the CEB 90 model and the ACI 209 model. The SAK model has the largest mean standard deviation of residuals for both time range groupings.

The B3 coefficient of variation (ω_{B3}%)of the models for all data sets was calculated using equations 3-4 to 3-7 and summarized in Table 4.5. The B3 model followed by the GZ and the ACI 209 models gave the best values.

Table 4.6 gives the results of the CEB statistical values in the six different time ranges for the coefficient of variation (V_i), the square error (F_i) and the deviation (M_i) calculated from equations 3-8 to 3-16. The smallest coefficient of variation was obtained by the B3 and the GZ models except for the time range of above 3 years. The values of M_i from the table indicates that the ACI 209 and SAK models overestimate the shrinkage for all time ranges. The values of M_i from the table show that except for age of 0-10 days and 1-2 years, the CEB 90 model underestimates for all other time ranges. The B3 model, the GZ model and the CEB 90 model gave lowest values for square error (F_i).

4.2.3 Discussion of Shrinkage Strain Analysis

Results of the various statistical evaluations using different time range groupings and ratings are summarized in Table 4.7. It is evident from Table 4.7 that predictions of the ACI 209 and SAK models for shrinkage strain residuals overestimate by 60% and 94% of the total number of data point values respectively. The ACI 209 overestimates 29% and underestimates 14% of the total number of data point values with residuals range larger than ±100 microstrain. The SAK model overestimates 76% and underestimates 2% of the total number of data point values with residuals larger than ±100 microstrain.

It can be observed from Table 4.7 that the B3, CEB 90 and the GZ models overestimate by 36%, 39% and 43% respectively and underestimates by 64%, 61% and 57% respectively of the total number of data point values. The B3 model overestimates 8% and underestimates 25% of the total number of data points with residual values larger than ±100 microstrain. The CEB 90 model overestimates the residuals 7% and underestimates 32% of the total number of data points with residuals larger than ±100 microstrain. The GZ model overestimates the residuals 13% and underestimates 25% of the total number of data points with residuals larger than ±100 microstrain.

It can be observed from Table 4.7 that the B3 model and the GZ give the low mean average of residuals in two and six time intervals respectively. The B3 model gives low standard deviation of residuals followed by the GZ model. Figures 4.20 and 4.21 compare the shrinkage strain statistical values of the B3 coefficient of variation (ω_{B3}%), the CEB mean coefficient of variation (V_{CEB}%), the CEB mean square error (F_{CEB}%) and the CEB mean deviation (M_{CEB}). It can be observed from Table 4.7 and Figures 4.20 and 4.21 that the B3 model and the GZ model performed well for the B3 coefficient of variation, the CEB mean coefficient of variation and the CEB mean square error. For the mean deviation method the GZ model followed by the B3 model and the CEB 90 model performed best when compared to the other models.

In Table 4.7 the rating of a model in a given category is shown in brackets. A rating of [1] or [2] for a given model indicates the model performed best in that given category. If a model receives a rating of [1] or [2] then that model earns a credit of one point. The credit point are then added to evaluate the best model. The GZ model received a credit rating of 10/10, followed by the B3 model receiving a credit rating of 9/10. The ACI 209, the CEB 90 and the SAK model received a credit rating of 2/10, 2/10 and 0/10 respectively.

4.3 Analysis of Creep Compliance

The creep compliance values of all five models were calculated for all the experimental data points selected from the RILEM data bank. The residuals and error percentages were then calculated and plotted versus time for comparison. The number of residual points in different residual ranges were analyzed. The average and standard deviation of residuals and compliance were calculated for the two and six time range intervals. To further evaluate the accuracy of the models, the B3 coefficient of variation (ω_{B3}), the CEB coefficient of variation ($\mathbf{V}_{CEB}$), the mean square error ($\mathbf{F}_{CEB}$), and the mean deviation ($\mathbf{M}_{CEB}$) of the predicted creep compliance were calculated and analyzed.

4.3.1 Analysis of Creep Compliance Residuals

Figures 4.22 to 4.31 show the creep compliance residuals for all the five models for the short and long term duration. Residuals are the difference between the predicted model compliance values and the experimental compliance values. Positive residuals indicate that corresponding model values overestimated the creep. Negative residuals indicate that corresponding model values underestimated the creep.

Figures 4.22 and 4.23 show the creep compliance residuals for the ACI 209 model. It can be observed from the figures and Table 4.1 that the residuals underestimates most of the data points. The residuals varied from +0.35 to –0.844 microstrain/psi.

Figures 4.24 and 4.25 show the creep compliance residuals for the B3 model. It is evident from the figures and Table 4.1 that the creep compliance residuals of the B3 model are biased toward negative values. The range of residuals varied from +0.655 to –0.788 microstrain/psi.

Figures 4.26 and 4.27 show the creep compliance residuals for the CEB 90 model. It can be observed from the figures and Table 4.1 that the distribution of residuals for the CEB 90 model are also biased toward negative values. The residuals varied from +0.602 to –0.737 microstrain/psi.

Figures 4.28 and 4.29 show the creep compliance residuals for the GZ model. It is evident from the figures and Table 4.1 that there are more positive than negative creep compliance residuals for the GZ model. The residuals varied from +0.856 to –0.832 microstrain/psi.

Figures 4.30 and 4.31 show the creep compliance residuals for the SAK model. The figures and Table 4.1 indicates that the SAK model residuals had almost equal number of data points on either side of zero horizontal axis. The residuals varied from +2.0 to –0.708 microstrain/psi.

The error percentages of predicted compliance values for the five models are given in Figures 4.32 to 4.36. The error percentage for all the five models varied from +400% to –65%.

Distribution of residuals for all data points in the positive (overestimated) and negative (underestimated) range were given in Table 4.1. The number and percentage of creep compliance residuals in various ranges are summarized in Table 4.8 and shown in Figures 4.37 and 4.38. The residuals range of 0 to ±0.23 microstrain/psi is considered to be a low range for compliance. The white bar in the figures indicates the low residual range of 0 to ±0.23 microstrain/psi.

Table 4.1 indicates that the ACI 209 model overestimates approximately 24% and underestimates approximately 76% of the creep data point values for the short time duration. For the long time duration, the model overestimates and underestimates 23% and 77% respectively. It can be observed from Table 4.8 and Figures 4.37 and 4.38 that for the long time duration, approximately 75% of the total residuals are in the low range of 0 to ±0.23 microstrain/psi. In addition approximately 2% of the residuals were in the range between +0.23 to +0.35 microstrain/psi and approximately 23% of the residuals were in the range of –0.23 to –0.844 microstrain/psi.

For the B3 model, Table 4.1 shows that the model overestimates 42% and underestimates 58% of the data point values in both the short and long time duration. It can be observed from Table 4.8 and Figures 4.37 and 4.38, for the long time duration, approximately 84% of the residuals were in the low range of 0 to ±0.23 microstrain/psi. The model overestimates only 4% of the total data points with residuals between +0.23 and +0.655 microstrain/psi, and underestimates almost 12% of the total number of data points with residual values between –0.23 and –0.788 microstrain/psi.

For the CEB 90 model, Table 4.1 shows that the model overestimates 39% of the data point values and underestimates 61% in the short and long time duration. The model has 86% of the total residuals in the low range of 0 to ±0.23 microstrain/psi. Only 3% of the total number of data points were overestimated with residual values ranging between +0.23 and +0.602 microstrain/psi and almost 11% of the total number of data points were underestimated with residuals ranging between −0.23 and −0.737 microstrain/psi.

For the GZ model, it can be observed from Table 4.1 that the model overestimates 58% of the data point values and underestimates 42% in the short and long time duration. It is evident from Table 4.8 and Figures 4.37 and 4.38 that approximately 86% of the total residuals were in the low range of 0 to ±0.23 microstrain/psi. Also about 5% of the residuals were overestimated with residuals in the range +0.23 to +0.856 microstrain/psi and approximately 9% of them were underestimated with residuals between −0.23 and −0.832 microstrain/psi.

For the short and long time duration, the SAK model, overestimates the 47% of the data point values and underestimates 53%. Approximately 75% of the total residuals were in the residual range of 0 to ±0.23 microstrain/psi. Also about 16% of the residuals were in the range between +0.23 and +2.0 microstrain/psi, whereas approximately 9% of them were in the range between −0.23 and −0.708 microstrain/psi.

The distribution of the SAK model residuals is almost equal in the positive and negative ranges followed by the B3 and the GZ models. But the CEB 90 and the GZ models provide more percentage of residuals in the low residual range of 0 to

±0.23 microstrain/psi. The distribution of residuals for the ACI 209, B3, CEB 90 and the SAK tends to underestimate creep compliance whereas the GZ model tends to overestimate creep compliance.

4.3.2 Statistical Analysis of Creep Compliance

In this section the results of the average and standard deviation, the B3 coefficient of variation, the CEB coefficient of variation, the CEB mean square error, and the CEB mean deviation of creep compliance are given. The average of creep compliance and residuals of a given model were calculated and summarized in Tables 4.9 and 4.10. Tables 4.11 and 4.12 show the standard deviations of the residuals and compliance for two and six time range intervals. The average and standard deviation of creep compliance and creep compliance residuals are also plotted in Figures 4.39 through 4.42.

It is evident from Tables 4.9 and Figures 4.39 and 4.40 that the ACI 209 model gives low mean averages of compliance followed by the CEB 90 model. It can be also observed from Table 4.10 and Figures 4.39 and 4.40 that the GZ model followed by the B3 and the CEB 90 models give low average of compliance residuals in the two and six time ranges. Tables 4.11 and 4.12 and Figures 4.41 and 4.42 indicates that the ACI 209 model and the CEB 90 model followed by the B3 and GZ models give a better standard deviation for creep compliance and residuals.

The B3 coefficient of variation for all data sets for creep compliance is given in Table 4.13. The GZ model performed well for this method with the smallest coefficient of variation followed by the CEB 90 and the B3 models.

Table 4.14 gives the statistical values of creep compliance calculated using the CEB method in six different time ranges. The coefficient of variation (V_i), the square error (F_i) and the deviation (M_i) are listed. The B3 model, the GZ model and the CEB 90 model give best values for the coefficient of variation (V_i). The value of M_i from the table indicates that the ACI 209 model underestimates and the GZ model overestimates for all time ranges. For the other three model the values of M_i fluctuates. For the square error (F_i), the table show that the CEB 90 model and the ACI 209 model give best values except for above 1100 days.

4.3.3 Discussion of Creep Compliance Analysis

Table 4.15 summarizes the results of various statistical evaluations of creep compliance and creep compliance residuals. It is evident from Table 4.15 that the predictions of the ACI 209 model for creep overestimate and underestimate the creep compliance data by 23% and 77% respectively in the long term duration. Approximately 25% of the total number of residual are larger than ±0.23 microstrain/psi (±25% of total distribution of residuals).

The B3 model overestimates and underestimates 42% and 58% of the total number of data point values respectively for the long time duration. Approximately 16% of the total number of residuals larger than ±0.23 microstrain/psi.

The CEB 90 model overestimates 39% and underestimates 61% of the total number of data point values for the long time duration. Approximately by 14% of the total number of residuals are larger than ±0.23 microstrain/psi.

The GZ model overestimates and underestimates 58% and 42% of the total number of data point values respectively for the long time duration. Approximately 14% of the total number of residuals are larger than ±0.23 microstrain/psi.

The SAK model overestimates and underestimates by 47% and 53% of the total number of data point values, with 25% of the total number of residuals larger than ±0.23 microstrain/psi.

It can be observed from the Tables 4.15 that the GZ model followed by the B3 model and the CEB 90 model gave low negative mean average of residuals. For the mean standard deviation of residuals, the CEB 90 followed by the ACI 209 model performed best. The ACI 209 and the CEB 90 models also performed best for the mean average and mean standard deviation of compliance when compared to the other three models.

Figures 4.43 and 4.44 compare the B3 coefficient of variation, the CEB mean coefficient of variation, the CEB mean square error, and the CEB mean deviation. Table 4.15 and the figures show that the B3, the GZ and the CEB 90 models performed best for the CEB mean coefficient of variation and the B3 coefficient of variation. It can be observed from Table 4.15 that the CEB 90 model performed best for the CEB mean square error and the B3 model performed best for the CEB mean deviation.

The rating of a model in a given category is shown in brackets in Table 4.15. A rating of [1] or [2] for a given model indicates the model performed best in that given category. If a model receives a rating of [1] or [2] then that model earns a credit of one point. The credit points are added to evaluate the best model. It can be observed from Table 4.15 that the CEB 90 model earned a higher accumulated rating of 11/12, while the

B3 model and the GZ model received a rating of 8/12 and 7/12 respectively. The ACI 209 and the SAK models received a rating of 5/12 and 1/12 respectively.

Table 4.1: Distribution of Number and Percentage of Residual Points for Shrinkage and Creep Models

Category	Residual Range	ACI 209	B3	CEB 90	GZ	SAK
Shrinkage 1209 points 0-1000 days	"+"	742 (62%)	438 (36%)	489 (40%)	**497 (41%)***	1126 (93%)
	"–"	467 (38%)	771 (64%)	720 (60%)	**712 (59%)***	83 (7%)
Shrinkage 1333 points 0-7000 days	"+"	790 (60%)	474 (36%)	518 (39%)	**569 (43%)***	1250 (94%)
	"–"	543 (40%)	859 (64%)	815 (61%)	**764 (57%)***	83 (6%)
Category	**Residual Range**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
Creep Compliance 2083 points 0-1000 days	"+"	498 (24%)	865 (42%)	808 (39%)	1201 (58%)	**975 (47%)***
	"–"	1585 (76%)	1218 (58%)	1275 (61%)	882 (42%)	**1108 (53%)***
Creep Compliance 2200 points 0-7000 days	"+"	506 (23%)	935 (42%)	851 (39%)	1274 (58%)	**1034 (47%)***
	"–"	1694 (77%)	1265 (58%)	1349 (61%)	926 (42%)	**1166 (53%)***

Note 1: * indicates best performance
Note 2: Values in the brackets indicates the percentage of residuals in that particular range to the total number of residual points.
+ = Model overestimates data, – = Model underestimates data

Table 4.2: Distribution of Number and Percentage of Residuals in Various Ranges for Shrinkage Strain

Residual Range in microstrain	Number of Residual Points (Percentage) 0-1000 days (Total Number of Points = 1209)				
	ACI 209	B3	CEB 90	GZ	SAK
0 to + 100	387 (32%)	333 (28%)	**399 (33%)***	360 (30%)	223 (18%)
0 to – 100	305 (25%)	**472 (39%)***	334 (28%)	399 (33%)	60 (5%)
Over + 100	355 (30%)	105 (9%)	**90 (7%)***	137 (11%)	903 (75%)
Over – 100	162 (13%)	299 (24%)	386 (32%)	313 (26%)	**23 (2%)***
0 to ± 100	692 (57%)	**805 (67%)***	733 (61%)	759 (63%)	283 (23%)
Over ± 100	517 (43%)	**404 (33%)***	476 (39%)	450 (37%)	926 (77%)
Residuals Range in microstrain	**Number of Residual Points (Percentage) 0-7000 days (Total Number of Points = 1333)**				
	ACI 209	**B3**	**CEB 90**	**GZ**	**SAK**
0 to + 100	411 (31%)	368 (28%)	**427 (32%)***	396 (30%)	229 (17%)
0 to – 100	355 (26%)	**523 (39%)***	388 (29%)	427 (32%)	60 (5%)
Over + 100	379 (29%)	106 (8%)	**91 (7%)***	173 (13%)	1021 (76%)
Over – 100	188 (14%)	336 (25%)	427 (32%)	337 (25%)	**23 (2%)***
0 to ± 100	766 (57%)	**891 (67%)***	815 (61%)	823 (62%)	289 (22%)
Over ± 100	567 (43%)	**442 (33%)***	518 (39%)	510 (38%)	1044 (78%)

Note 1: * indicates best performance
Note 2: Values in the brackets indicates the percentage of residuals in that particular range to the total number of residual points.

Table 4.3: Average of Shrinkage Strain Residuals for Five Models Grouped into Two and Six Time Ranges

		Average of Residuals for Models in microstrain				
Two Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-1000 days	1209	46	–28	–53	–35	226
0-7000 days	1333	40	–30	–54	–30	231
Mean Average		43	**–29***	–54	–33	229
Six Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-10 days	204	–7	15	13	–12	104
10-100 days	445	39	27	–46	–30	216
100-1 year	358	83	–43	–90	–65	286
1-2 years	151	72	–36	–55	–9	266
2-3years	74	6	–64	–81	–2	304
Above 3 years	101	–27	–65	–75	7	224
Mean Average		27	–27	–55	**–19***	233

Note: * indicates best performance

Table 4.4: Standard Deviation of Shrinkage Strain Residuals for Five Models Grouped into Two and Six Time Ranges

		Standard Deviation of Residuals for Models in microstrain				
Two Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-1000 days	1209	165	118	138	123	185
0-7000 days	1333	161	116	135	124	180
Mean Standard deviation		163	**117***	137	124	183
Six Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-10 days	204	62	41	142	36	67
10-100 days	445	142	92	109	96	152
100-1 year	358	187	141	170	162	198
1-2 years	151	230	174	179	146	233
2-3years	74	149	97	125	121	152
Above 3 years	101	109	98	102	124	114
Mean Standard deviation		146	**107***	121	114	153

Note: * indicates best performance

Table 4.5: The B3 Coefficient of Variation for Shrinkage Strain for Five Models

ACI 209	**B3**	**CEB 90**	**GZ**	**SAK**
46%	**44%***	49.2%	44.6%	55%

Note: * indicates best performance

Table 4.6: Shrinkage Strain Coefficient of Variation, Square Error and Deviation for the CEB Method

		ACI 209	B3	CEB 90	GZ	SAK
0-10 days 204 data points	V_i %	75	49	52	**46***	138
	F_i %	144	130	145	**77***	471
	M_i	1.43	1.7	1.67	**0.98***	4.0
10-100 days 445 data points	V_i %	44	**29***	39	34	77
	F_i %	96	46	**41***	42	187
	M_i	1.43	**0.99***	0.94	**0.99***	2.18
100 days-1 years 358 data points	V_i %	36	**29***	39	36	66
	F_i %	128	75	62	**50***	194
	M_i	1.42	**1.0***	0.91	0.97	2.0
1-2 years 151 data points	V_i %	34	29	31	**25***	70
	F_i %	168	100	83	**60***	251
	M_i	1.47	1.1	**1.05***	1.1	2.16
2-3 years 74 data points	V_i %	26	**20***	27	22	57
	F_i %	35	**17***	22	23	76
	M_i	1.1	0.91	0.90	**1.05***	1.62
Above 3 years 101 data points	V_i %	**18***	19	20	20	47
	F_i %	23	**17***	18	21	57
	M_i	**1.0***	0.91	0.91	1.04	1.5

Note: * indicates best performance

Table 4.7: Summary of Results and Rating for Shrinkage Strain

Category	Time Range	ACI 209	B3	CEB 90	GZ	SAK
1.Distribution of Residuals "+" range "–" range	2	**60%** **40%** [2]	36% 64% [4]	39% 61% [3]	**43%** **57%** [1]	94% 6% [5]
2.Residual Range Outside + 100 microstrain – 100 microstrain	2	29% 14% [4]	**8%** **25%** [1]	7% 32% [3]	**13%** **25%** [2]	76% 2% [5]
3. Mean Average of Residuals (microstrain)	2	43 [3]	**–29** [1]	–54 [4]	**–33** [2]	229 [5]
4. Mean Standard Deviation of Residuals (microstrain)	2	163 [4]	**117** [1]	137 [3]	**124** [2]	183 [5]
5. Mean Average of Residuals (microstrain)	6	**27** [2]	**–27** [2]	–55 [3]	**–19** [1]	233 [4]
6.Mean Standard Deviation of residuals (microstrain)	6	146 [4]	**107** [1]	121 [3]	**114** [2]	153 [5]
7. Mean Coefficient of Variation, V_{CEB}%	6	43 [4]	**31** [1]	36 [3]	**32** [2]	81 [5]
8.Mean Square Error, F_{CEB} %	6	112 [3]	**76** [2]	**76** [2]	**50** [1]	247 [4]
9. Mean Deviation, M_{CEB}	6	1.3 [3]	**1.1** [2]	**1.12** [2]	**1.02** [1]	2.2 [4]
10. Coefficient of Variation, ω_{B3}%	—	46 [3]	**44** [1]	49.2 [4]	**44.6** [2]	55 [5]
Number of Categories with rating 1 or 2		**[2]**	**[9]**	**[2]**	**[10]**	**[0]**

Note: Rating of Model is given in brackets ([1] - Best, [5] - Worst)

Table 4.8: Distribution of Number and Percentage of Residuals in Various Ranges for Creep Compliance

Residual Range in microstrain/psi	Number of Residual Points (Percentage) 0-1000 days (Total Number of Points = 2083)				
	ACI 209	B3	CEB 90	GZ	SAK
0 to + 0.23	457(22%)	788(38%)	742(36%)	**1097(53%)***	642(31%)
0 to – 0.23	**1129(54%)***	965(46%)	1044(50%)	690(33%)	933(45%)
Over + 0.23	**41(2%)***	77(4%)	66(3%)	104(5%)	333(16%)
Over – 0.23	456(22%)	253(12%)	231(11%)	191(9%)	**175(8%)***
0 to ± 0.23	1586(76%)	1753(84%)	**1786(86%)***	**1787(86%)***	1575(76%)
Over ± 0.23	497(24%)	330(16%)	**297(14%)***	**296(14%)***	508(24%)
Residuals Range microstrain/psi	**Number of Residuals (Percentage) 0-7000 days (Total Number of Points = 2200)**				
	ACI 209	**B3**	**CEB 90**	**GZ**	**SAK**
0 to + 0.23	465(21%)	858(39%)	785(36%)	**1160(53%)***	676(31%)
0 to – 0.23	**1187(54%)***	992(45%)	1094(50%)	720(33%)	968(44%)
Over + 0.23	**41(2%)***	77(4%)	66(3%)	114(5%)	358(16%)
Over – 0.23	507(23%)	273(12%)	255(11%)	**205(9%)***	**198(9%)***
0 to ± 0.23	1652(75%)	1850(84%)	**1879(86%)***	**1880(86%)***	1644(75%)
Over ± 0.23	548(25%)	350(16%)	**321(14%)***	**320(14%)***	556(25%)

Note 1: * indicates best performance
Note 2: Values in the brackets indicates the percentage of residuals in that particular range to the total number of residual points.
Note 3: ± 0.23 microstrain/psi indicates ±25% of total distribution of residuals

Table 4.9: Average of Creep Compliance for Five Creep Models

		Average of Creep Compliance for Model in microstrain/psi				
Two Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-1000 days	2083	0.43	0.49	0.49	0.54	0.67
0-7000 days	2200	0.43	0.51	0.49	0.56	0.67
Mean Average		**0.43***	0.50	0.49	0.55	0.67

Note: * indicates best performance

Table 4.10: Average of Creep Compliance Residuals for Five Models Grouped into Two and Six Time Ranges

		Average of Residuals for Models in microstrain/psi				
Two Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-1000 days	2083	−0.12	−0.050	−0.051	−0.0012	0.067
0-7000 days	2200	−0.126	−0.049	−0.050	−0.0004	0.076
Mean Average		−0.12	−0.050	−0.051	**−0.001***	0.072
Six Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-10 days	488	−0.06	−0.026	−0.03	0.42	−0.05
10-100 days	706	−0.10	−0.06	−0.05	−0.0021	0.06
100-1 year	570	−0.135	−0.045	−0.048	−0.014	0.13
1-2 years	227	−0.22	−0.08	−0.06	−0.048	0.13
2-3 years	107	−0.21	−0.046	−0.05	−0.016	0.23
Above 3 years	102	−0.25	−0.04	−0.10	0.011	0.26
Mean Average		−0.16	−0.05	−0.05	**−0.004***	0.13

Note: * indicates best performance

Table 4.11: Standard Deviation of Creep Compliance for Five Models

		Standard deviation of Creep Compliance for Models in microstrain/psi				
Two Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-1000 days	2083	0.11	0.17	0.16	0.17	0.96
0-7000 days	2200	0.11	0.18	0.17	0.19	0.95
Mean Standard Deviation		**0.11***	0.18	0.17	0.18	0.96

Note: * indicates best performance

Table 4.12: Standard Deviation of Creep Compliance Residuals for Five Models Grouped into Two and Six Time Ranges

		Standard Deviation of Residuals for Models in microstrain/psi				
Two Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-1000 days	2083	0.18	0.18	0.17	0.18	0.35
0-7000 days	2200	0.18	0.19	0.17	0.19	0.39
Mean Standard Deviation		0.18	0.19	**0.17***	0.19	0.37
Six Time Ranges	**Data Points**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
0-10 days	488	0.10	0.10	0.09	0.10	0.11
10-100 days	706	0.16	0.16	0.15	0.16	0.29
100-1 year	570	0.20	0.22	0.20	0.20	0.39
1-2 years	227	0.23	0.25	0.24	0.25	0.52
2-3 years	107	0.21	0.23	0.22	0.26	0.62
Above 3 years	102	0.20	0.19	0.20	0.17	0.72
Mean Standard Deviation		**0.18***	0.19	**0.18***	0.19	0.44

Note: * indicates best performance

Table 4.13: The B3 Coefficient of Variation for Creep Compliance for Five Models

ACI 209	B3	CEB 90	GZ	SAK
60.3%	43.4%	43.3%	**37.5%***	48.8%

Note: * indicates best performance

Table 4.14: Creep Compliance Coefficient of Variation, Square Error and Deviation for the CEB Method

		ACI 209	B3	CEB 90	GZ	SAK
$t \le 10$ days 488 data points	V_i %	33	29.7	**28.3***	30.4	76.2
	F_i %	27.2	27.8	**26.4***	36.6	47.6
	M_i	0.89	**0.98***	**0.98***	1.2	0.93
$10 < t \le 100$ days 706 data points	V_i %	37.1	33.8	**31.5***	**31.6***	251
	F_i %	34	**33***	**33.4***	35.6	123
	M_i	0.90	0.97	**0.99***	1.1	1.27
$100 < t \le 365$ days 570 data points	V_i %	39.6	34.9	33.1	**32***	130
	F_i %	**39.5***	46	41	42.2	89
	M_i	0.90	1.06	**1.02***	1.1	1.33
$365 < t \le 730$ days 227 data points	V_i %	42	34.7	34.9	**33.7***	69.3
	F_i %	**38.8***	44	40.8	47	76.7
	M_i	0.80	**1.0***	0.95	1.05	1.24
$730 < t \le 1100$ days 107 data points	V_i %	39.2	32.1	**31.5***	34.5	89
	F_i %	**33.7***	37.4	34.3	43.4	87.6
	M_i	0.80	**1.02***	0.96	1.06	1.35
$t > 1100$ days 102 data points	V_i %	40	24.6	29	**21.4***	94.4
	F_i %	31.8	21.7	23.4	**21.1***	86.6
	M_i	0.74	**1.0***	0.90	1.05	1.31

Note: * indicates best performance

Table 4.15: Summary of Results and Rating for Creep Compliance

Category	Time Range	ACI 209	B3	CEB 90	GZ	SAK
1.Distribution of Residuals "+" range "–" range	2	23% 77% [4]	**42%** **58%** [2]	39% 61% [3]	**58%** **42%** [2]	**47%** **53%** [1]
2.Residual Range Outside +0.23 microstrain/psi −0.23 microstrain/psi	2	2% 23% [3]	**4%** **12%** [2]	**3%** **11%** [1]	**5%** **9%** [1]	16% 9% [4]
3. Mean Average of Residuals (microstrain/psi)	2	–0.12 [4]	**–0.050** [2]	**–0.051** [2]	**–0.001** [1]	0.072 [3]
4. Mean Standard Deviation of residuals (microstrain/psi)	2	**0.18** [2]	0.19 [3]	**0.17** [1]	0.19 [3]	0.37 [4]
5. Mean Average of Compliance (microstrain/psi)	2	**0.43** [1]	0.50 [3]	**0.49** [2]	0.55 [4]	0.67 [5]
6. Mean Standard Deviation of Compliance (microstrain/psi)	2	**0.11** [1]	0.18 [3]	**0.17** [2]	0.18 [3]	0.96 [4]
7. Mean Average of Residuals (microstrain/psi)	6	–0.16 [4]	**–0.05** [2]	**–0.05** [2]	**–0.004** [1]	0.13 [3]
8.Mean Standard Deviation of Residuals (microstrain/psi)	6	**0.18** [1]	**0.19** [2]	**0.18** [1]	**0.19** [2]	0.44 [3]
9. Mean Coefficient of Variation, V_{CEB}%	6	38.6 [3]	**32** [2]	**31** [1]	**31** [1]	134 [4]
10.Mean Square Error, F_{CEB} %	6	**34.4** [2]	36 [3]	**33.5** [1]	38.6 [4]	88 [5]
11. Mean Deviation, M_{CEB}	6	0.84 [4]	**1.00** [1]	**0.97** [2]	1.10 [3]	1.24 [5]
12. Coefficient of Variation, ω_{B3}%	—	60.3 [4]	**43.4** [2]	**43.3** [2]	**37.5** [1]	48.8 [3]
Number of Categories with rating 1 or 2		[5]	[8]	[11]	[7]	[1]

Note: Rating of Model is given in brackets ([1] - Best, [5] - Worst)

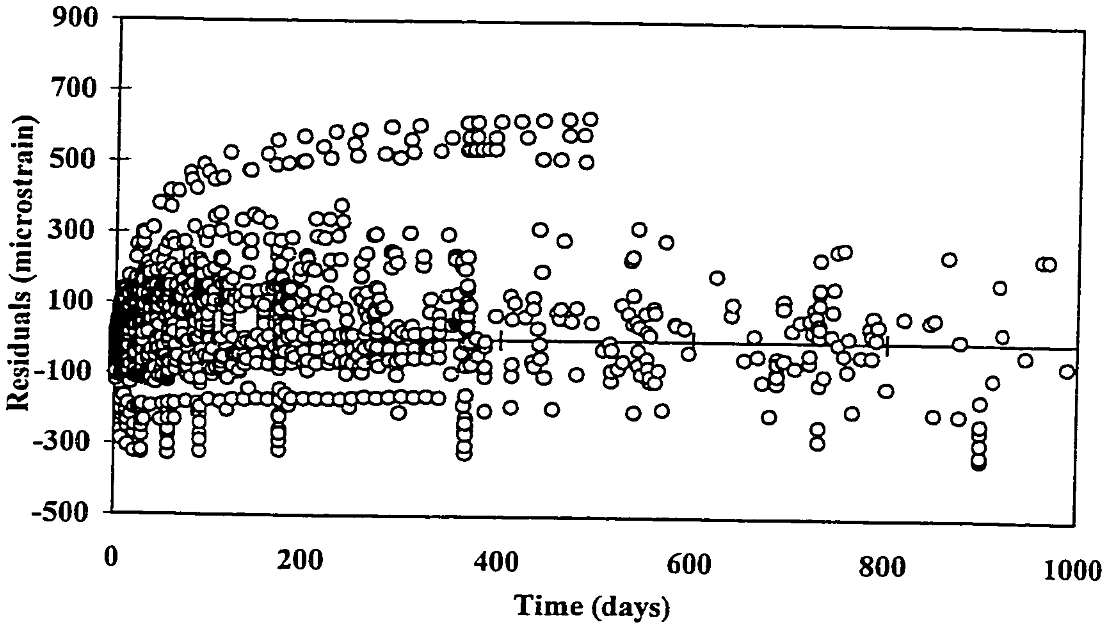


Figure 4.1: Shrinkage strain residuals for the ACI 209 model for short term duration (i.e. 0-1000 days)

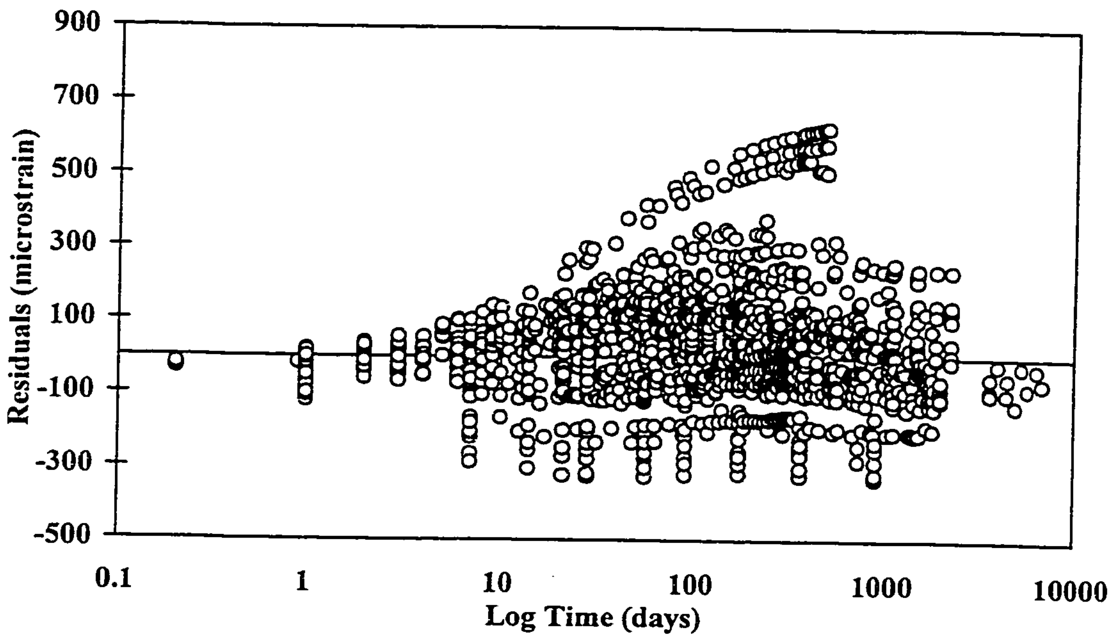


Figure 4.2: Shrinkage strain residuals for the ACI 209 model for long term duration (i.e. 0-7000 days)

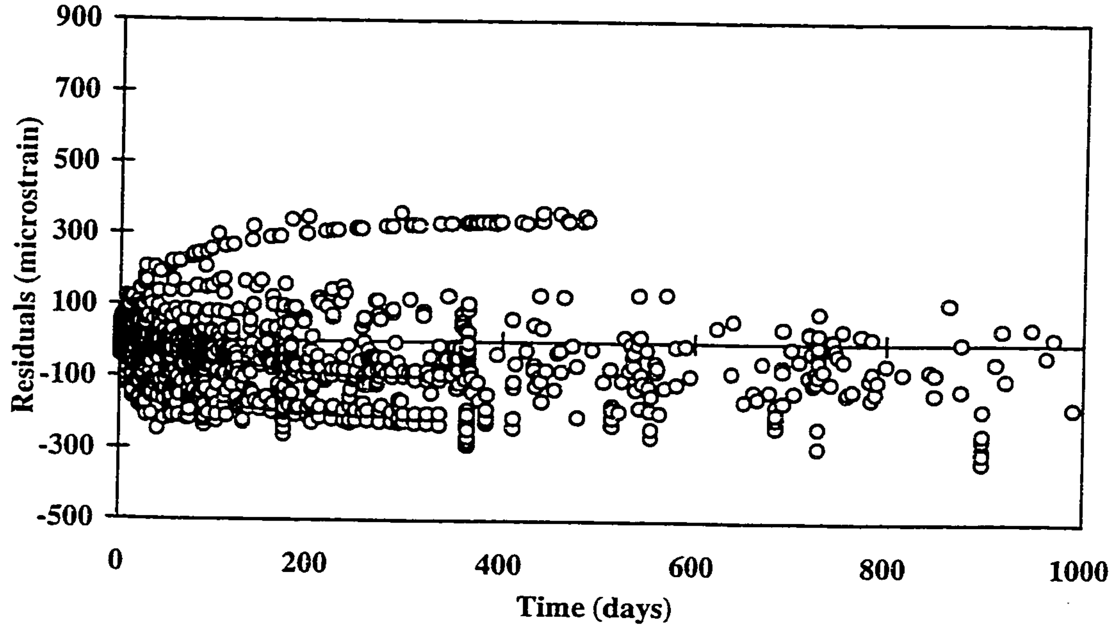


Figure 4.3: Shrinkage strain residuals for the B3 model for short term duration (i.e. 0-1000 days)

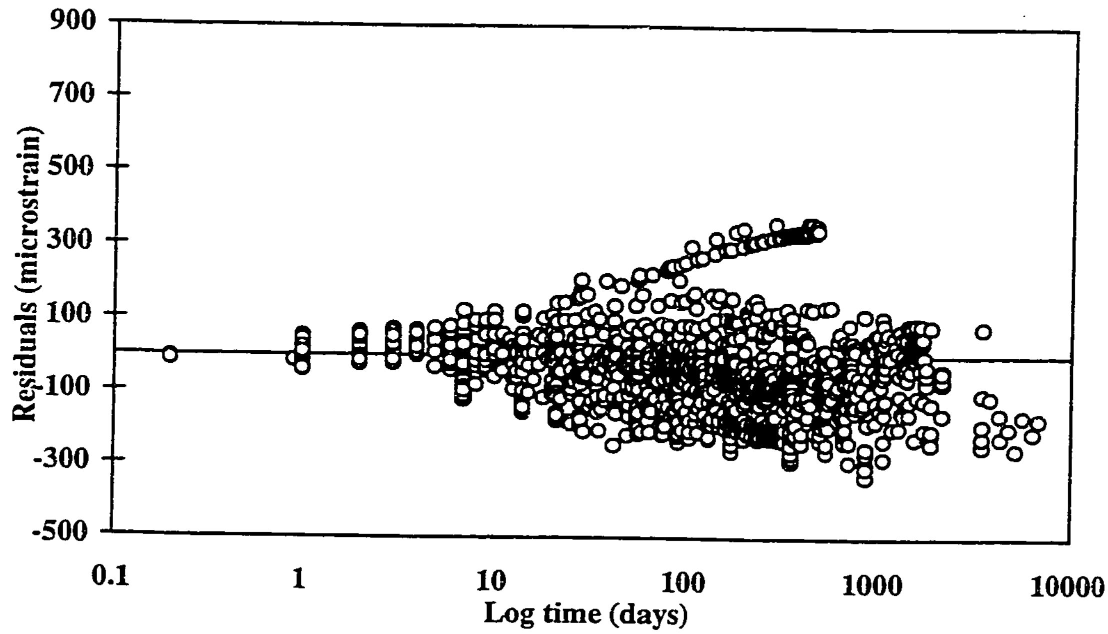


Figure 4.4: Shrinkage strain residuals for the B3 model for long term duration (i.e. 0-7000 days)

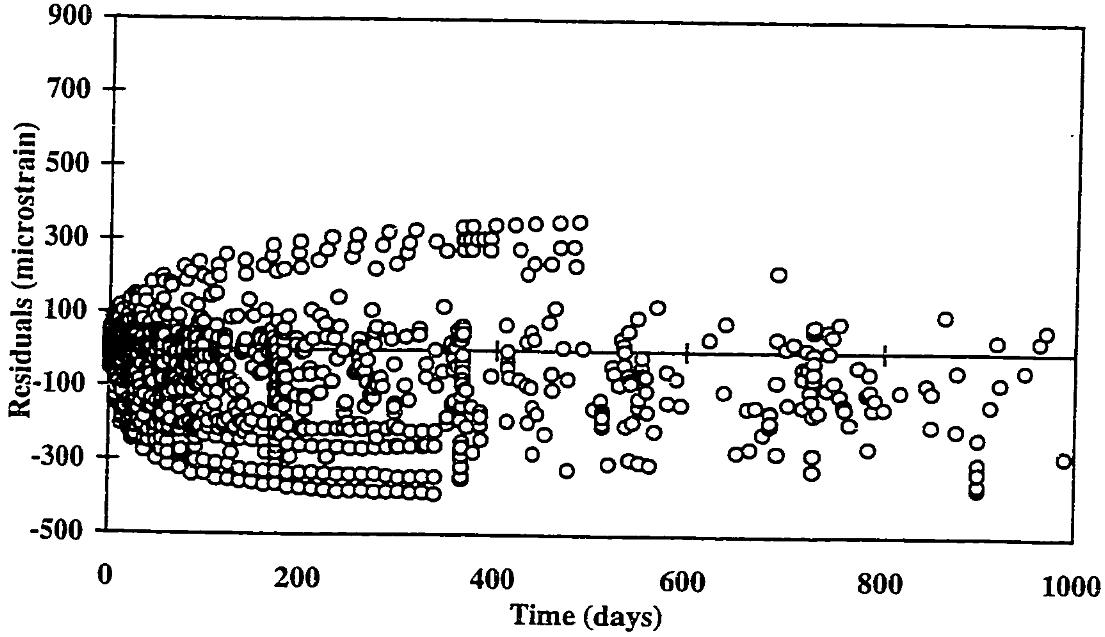


Figure 4.5: Shrinkage strain residuals for theCEB 90 model for short term duration (i.e. 0-1000 days)

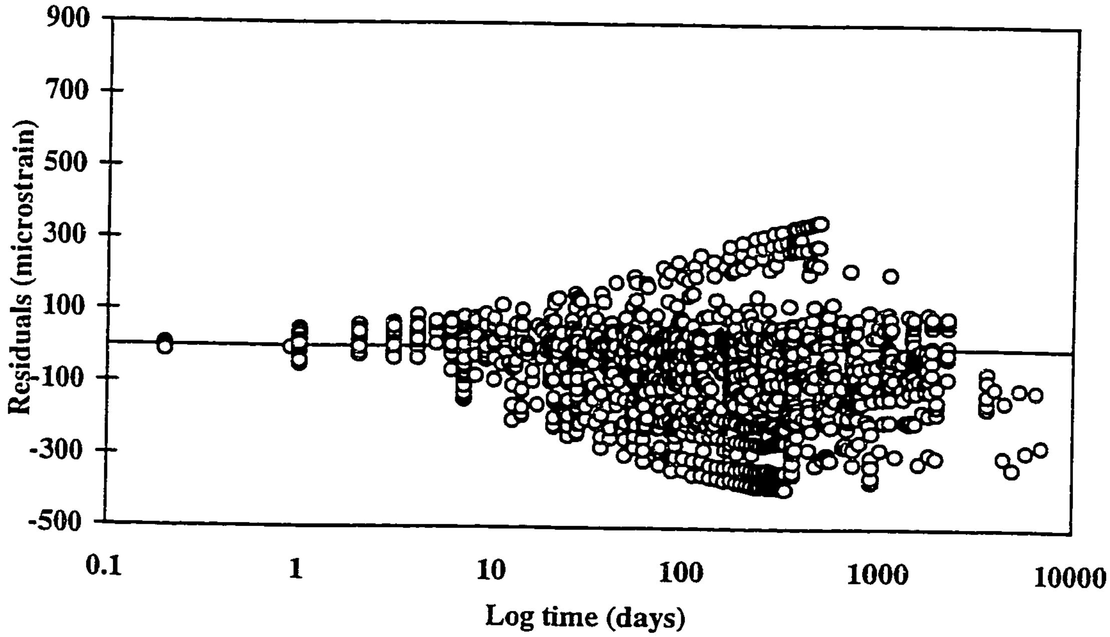


Figure 4.6: Shrinkage strain residuals for the CEB 90 model for long term duration (i.e. 0-7000 days)

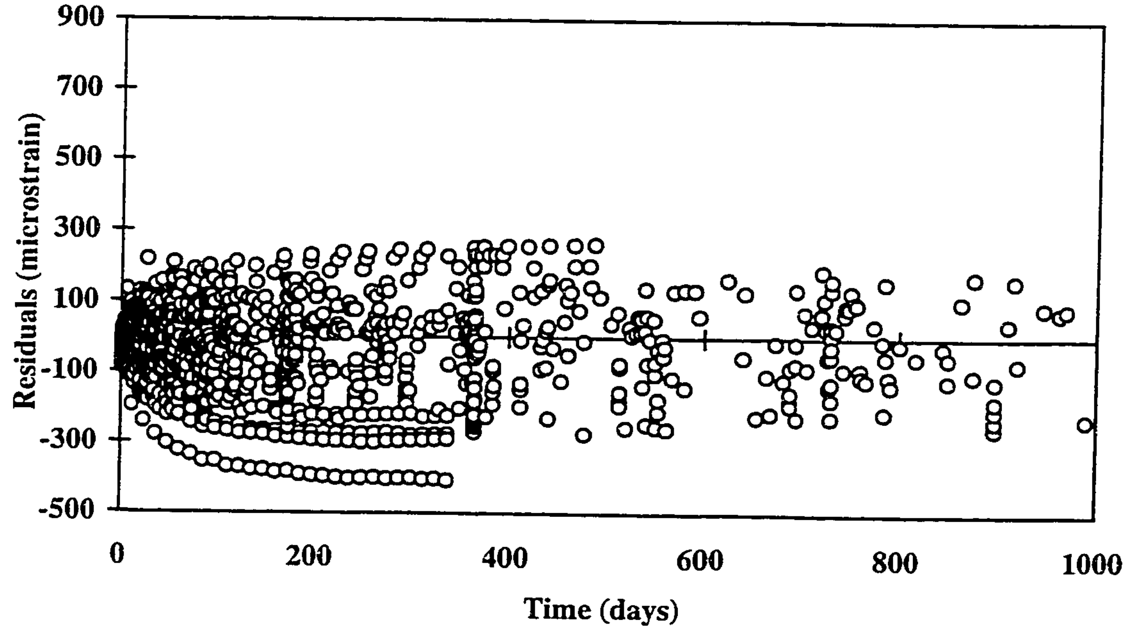


Figure 4.7: Shrinkage strain residuals for the GZ model for short term duration (i.e. 0-1000 days)

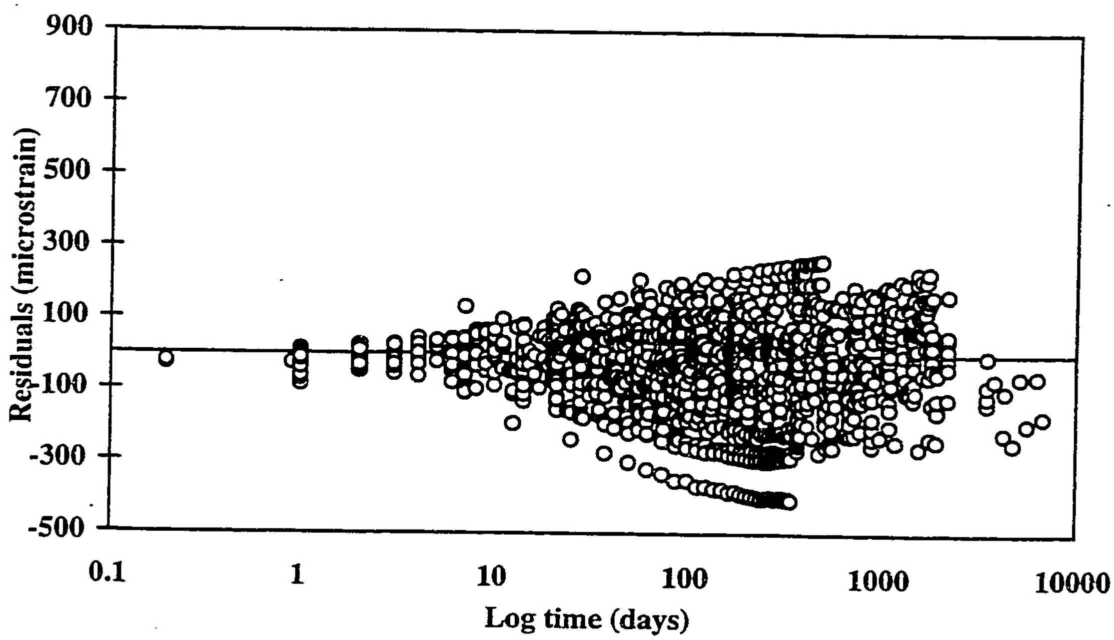


Figure 4.8: Shrinkage strain residuals for the GZ model for long term duration (i.e. 0-7000 days)

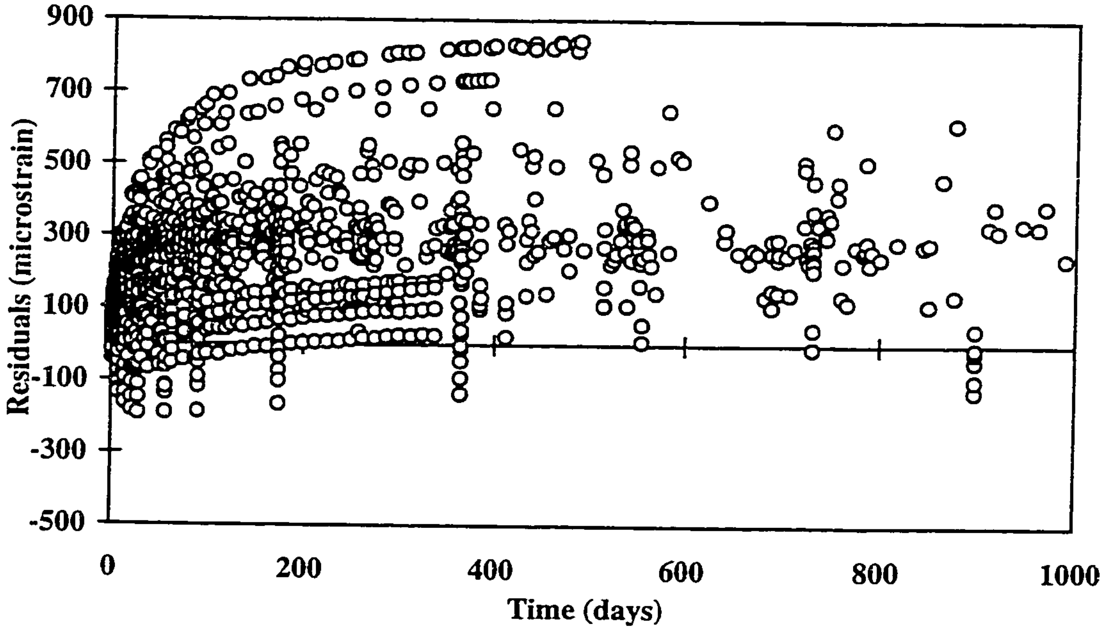


Figure 4.9: Shrinkage strain residuals for the SAK model for short term duration (i.e. 0-1000 days)

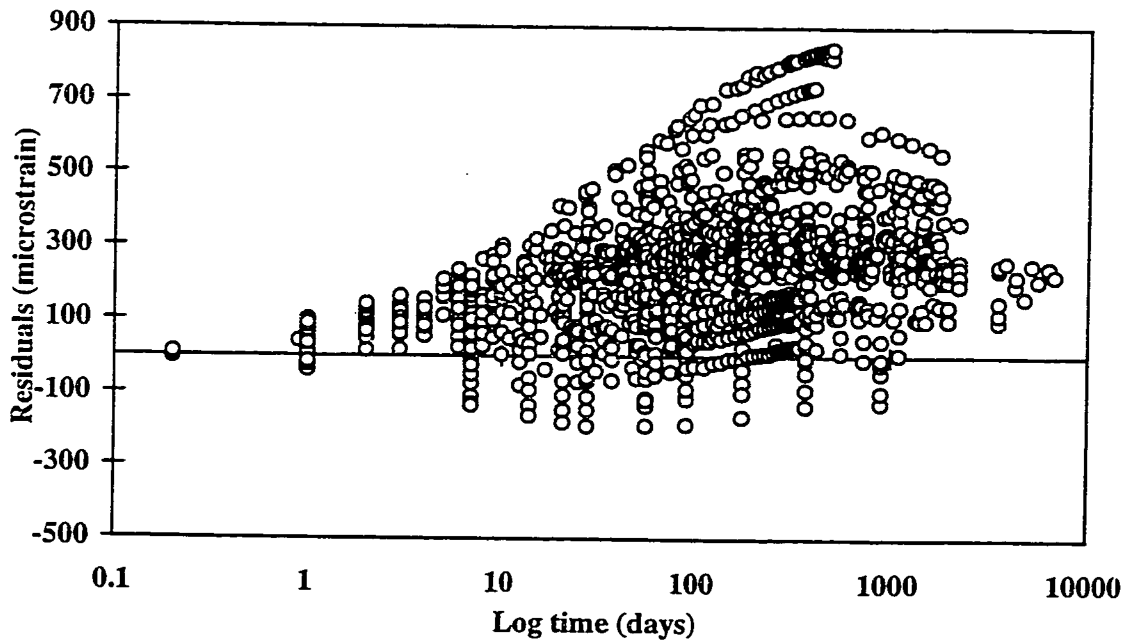


Figure 4.10: Shrinkage strain residuals for the SAK model for long term duration (i.e. 0-7000 days)

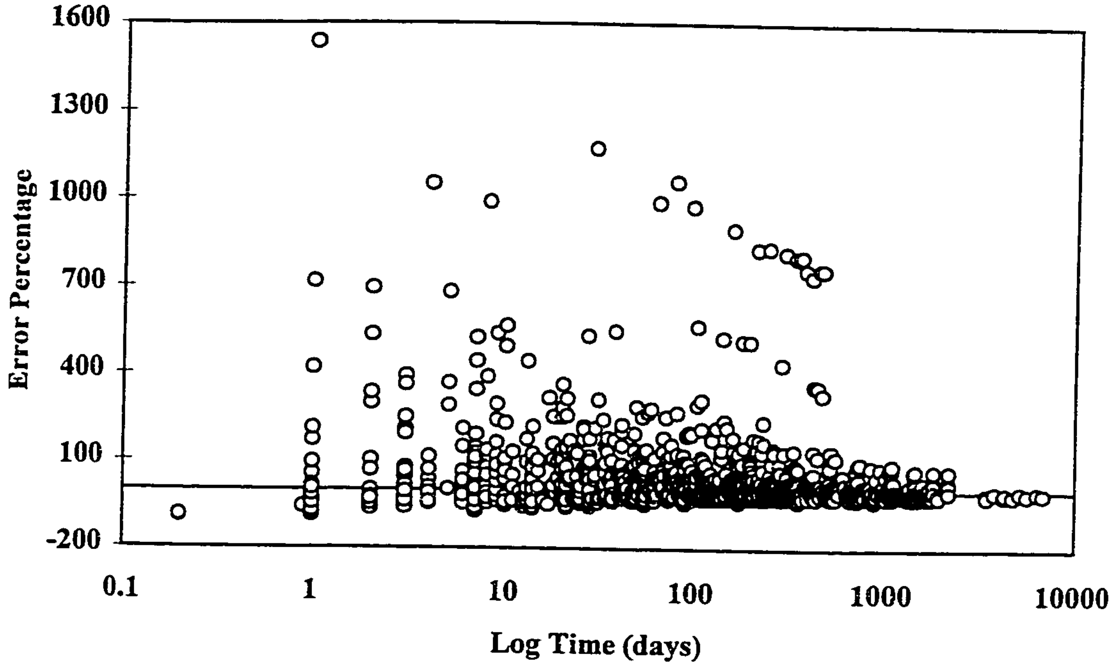


Figure 4.11: Shrinkage strain error percentage for the ACI 209 model for long term duration (i.e. 0-7000 days)

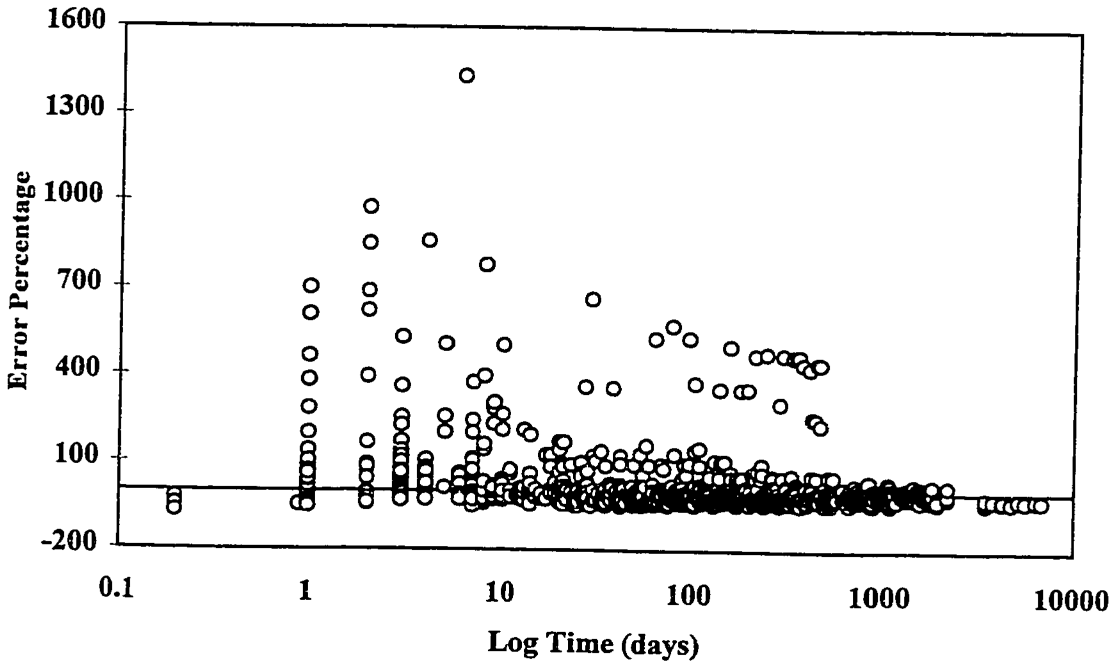


Figure 4.12: Shrinkage strain error percentage for the B3 model for long term duration (i.e. 0-7000 days)

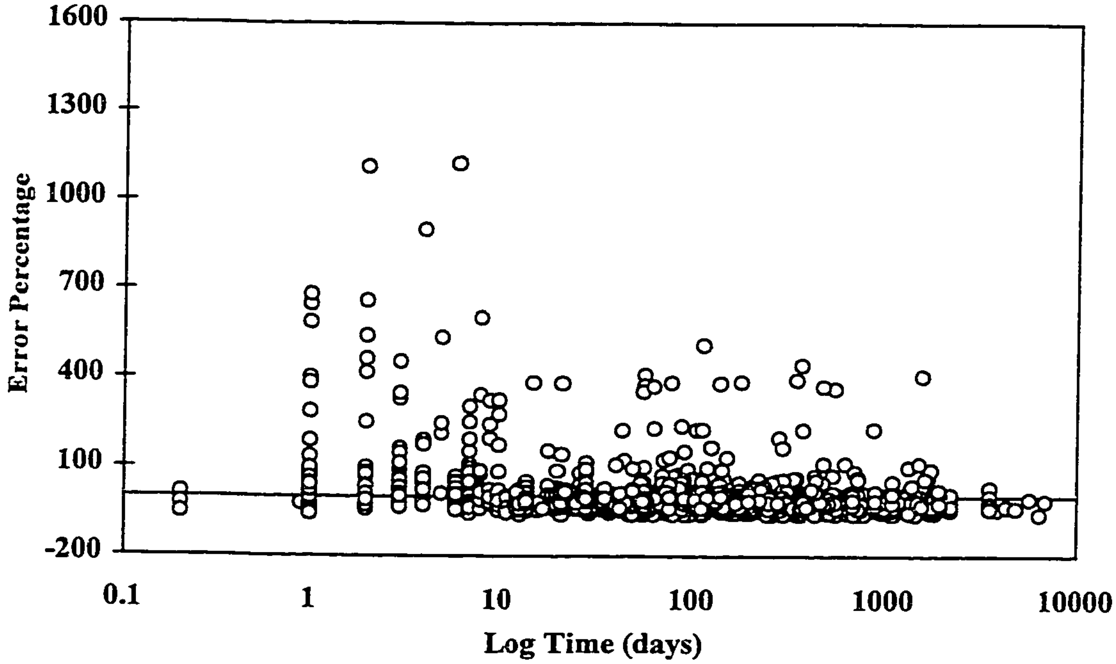


Figure 4.13: Shrinkage strain error percentage for the CEB 90 model for long term duration (i.e. 0-7000 days)

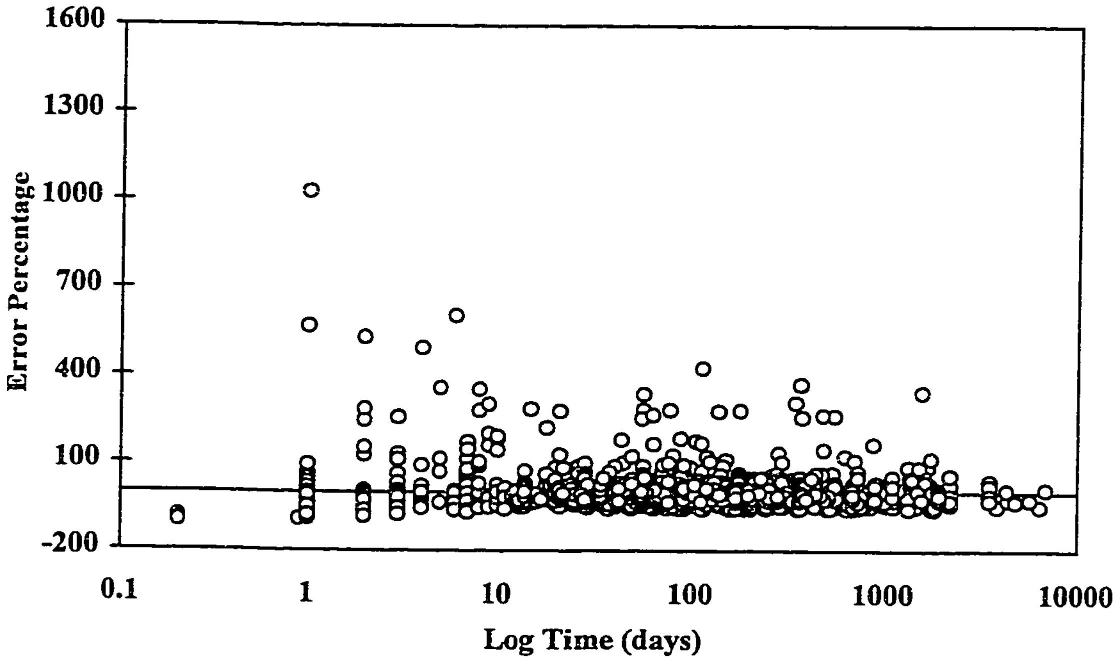


Figure 4.14: Shrinkage strain error percentage for the GZ model for long term duration (i.e. 0-7000 days)

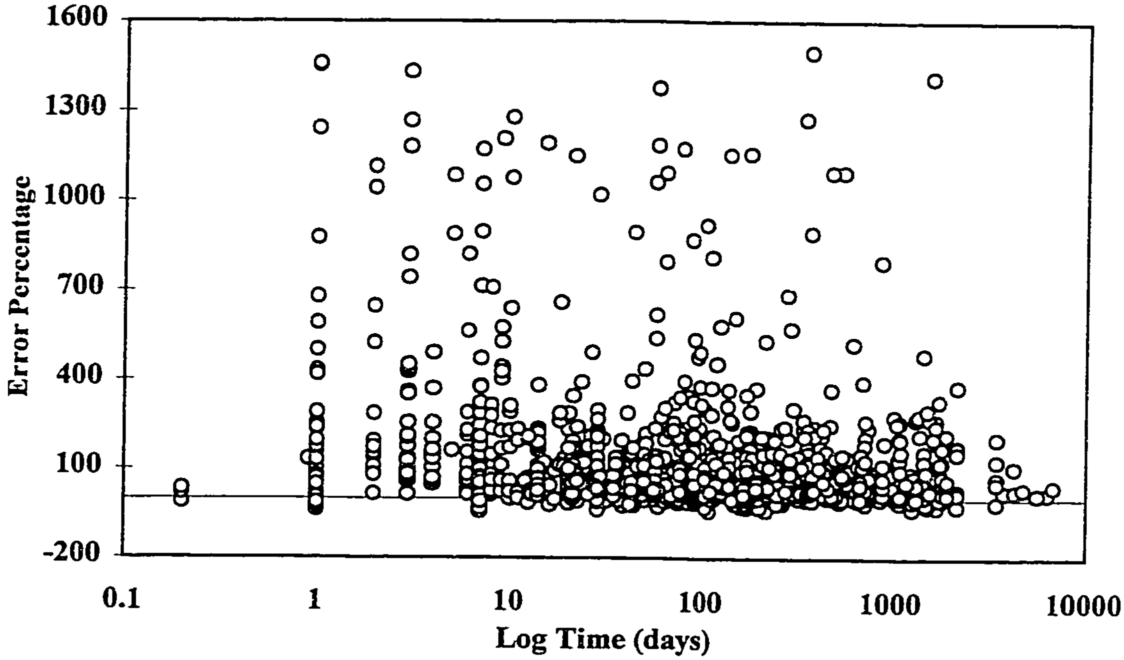


Figure 4.15: Shrinkage strain error percentage for the SAK model for long term duration (i.e. 0-7000 days)

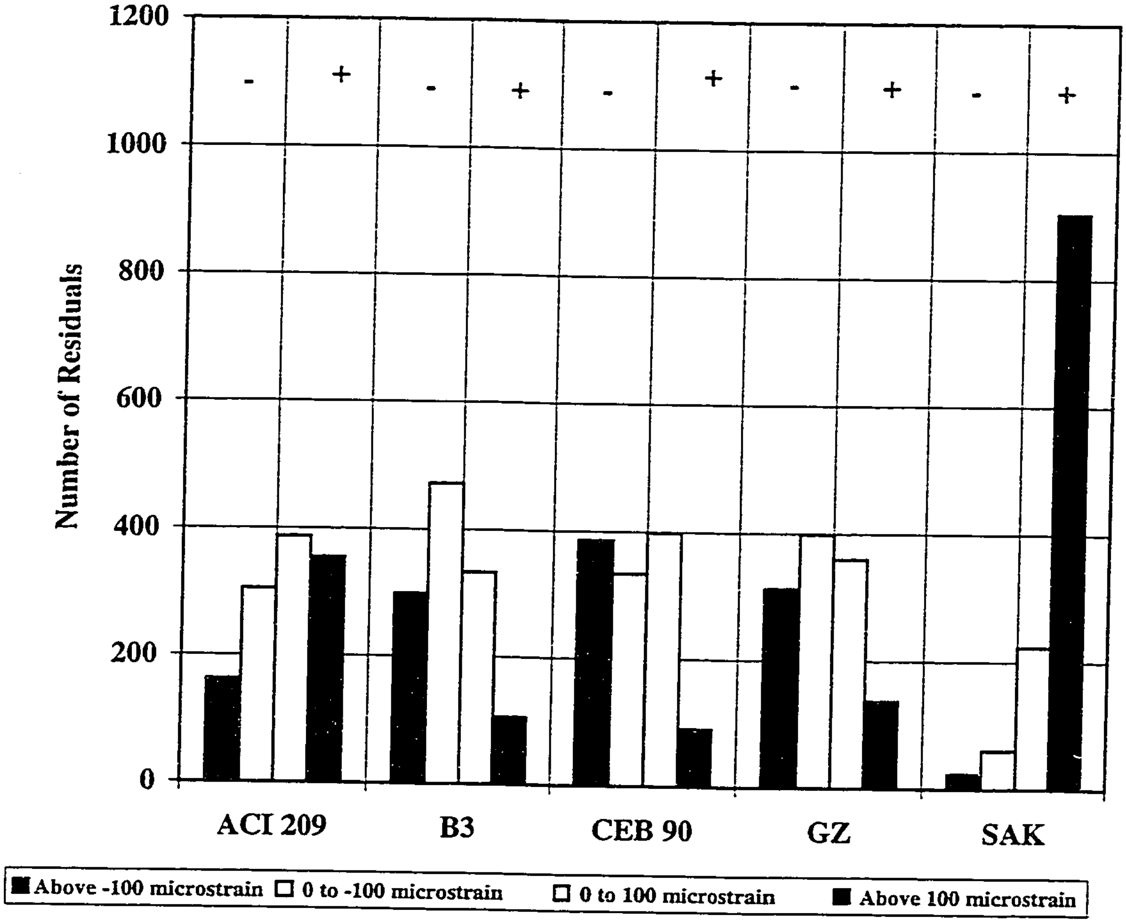


Figure 4.16: Distribution of residual points for shrinkage strain for 0-1000 days grouped into various residual ranges

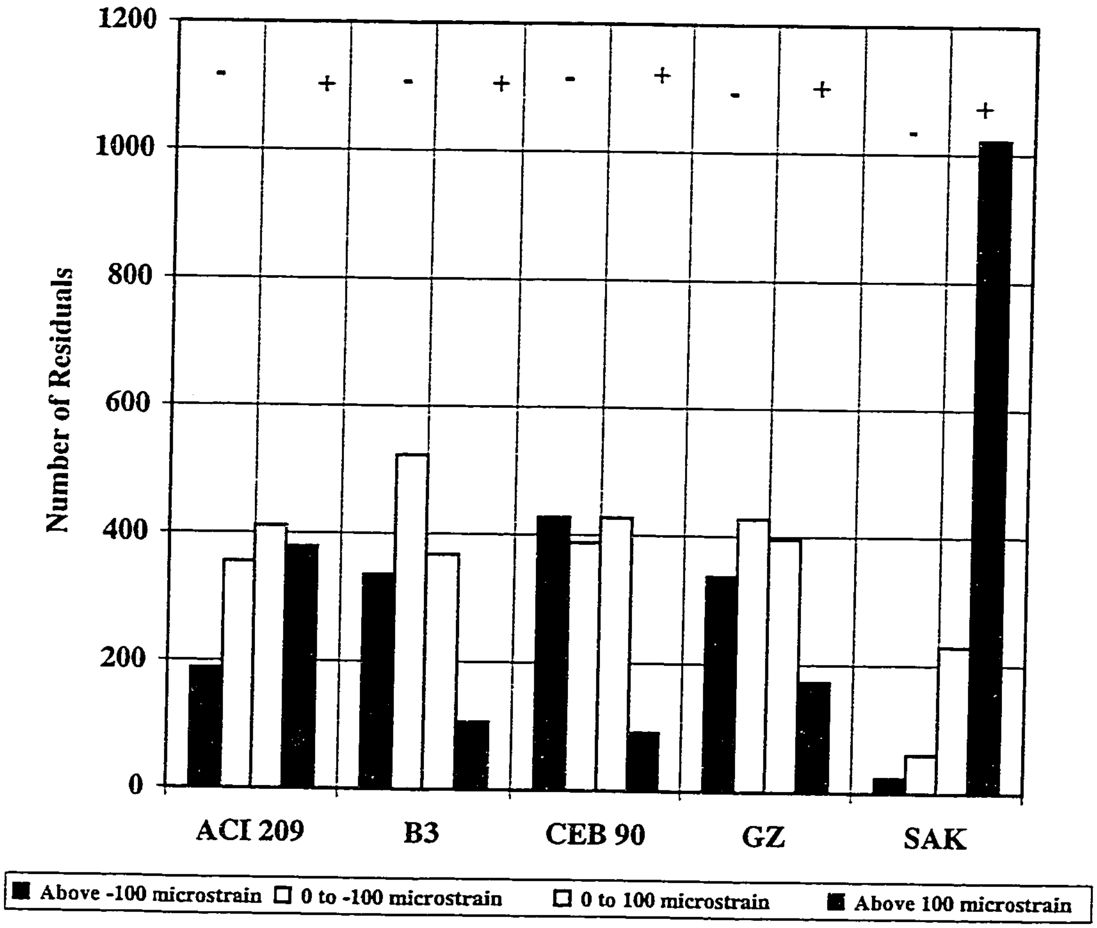


Figure 4.17: Distribution of residual points for shrinkage strain for 0-7000 days grouped into various residual ranges

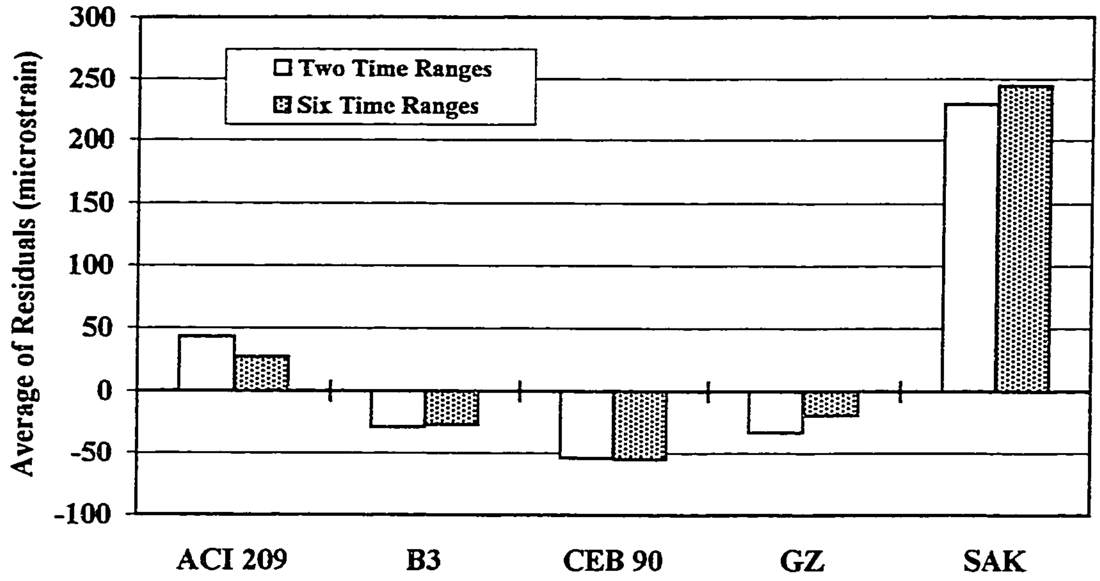


Figure 4.18: Average shrinkage strain residuals for five models grouped into two and six time ranges

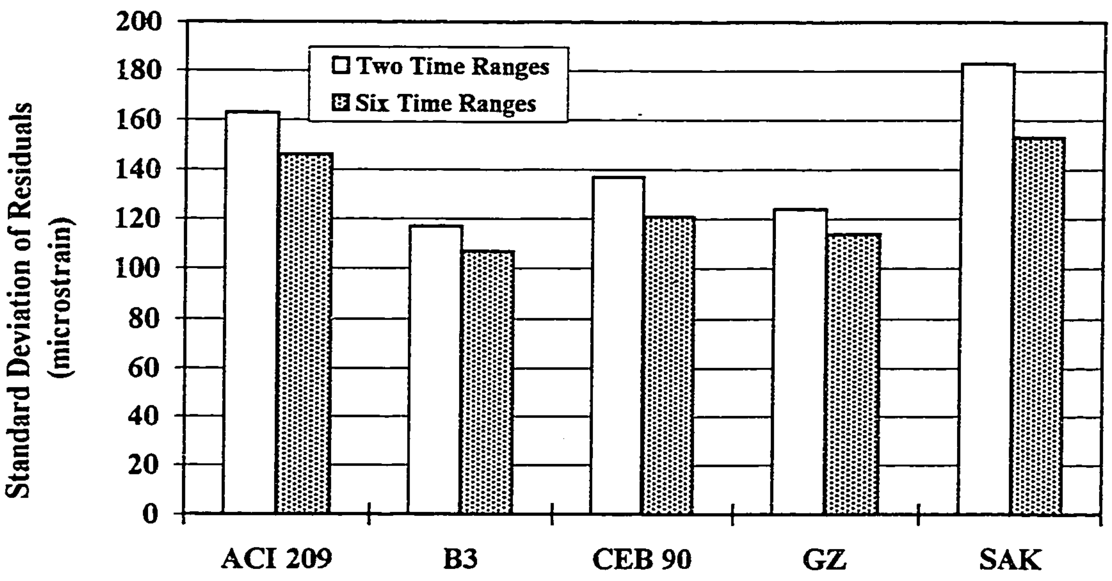


Figure 4.19: Standard deviation shrinkage strain residuals for five models grouped into two and six time ranges

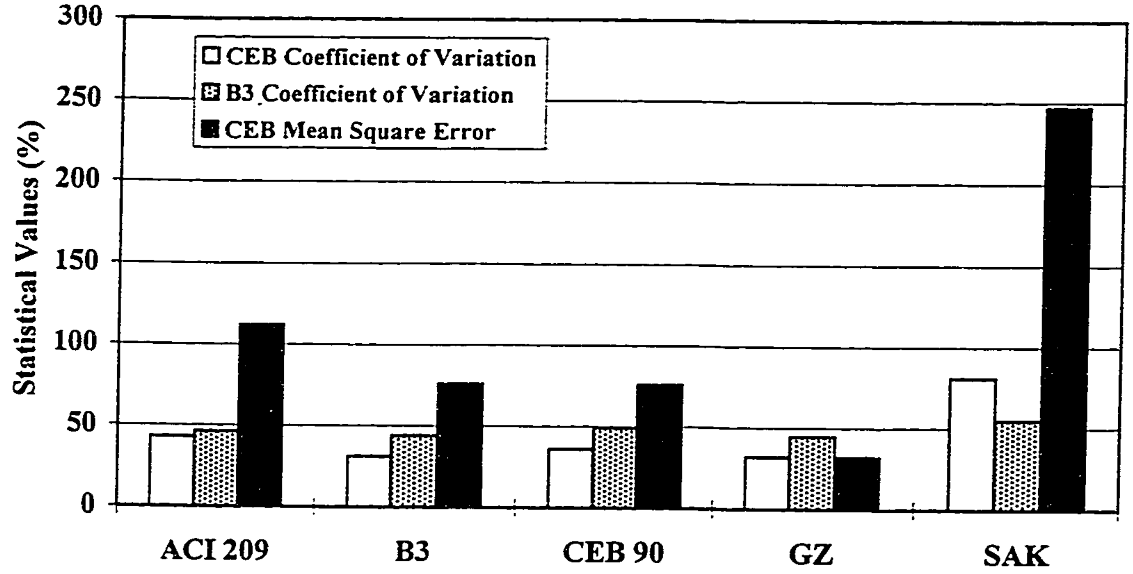


Figure 4.20: Coefficient of variation and mean square error for five models for shrinkage strain

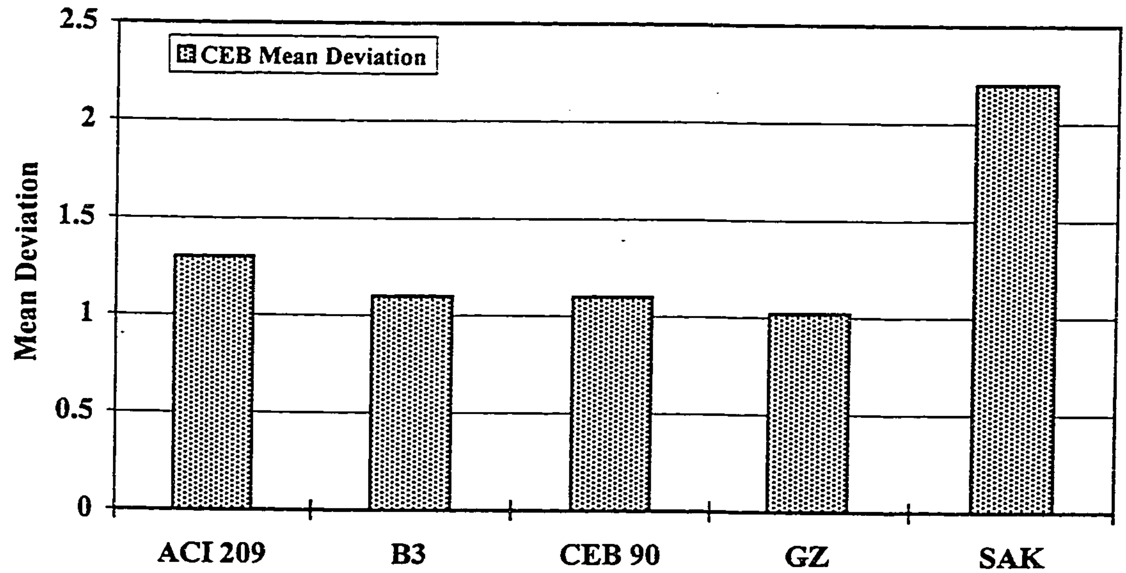


Figure 4.21: Mean deviation for five models for shrinkage strain

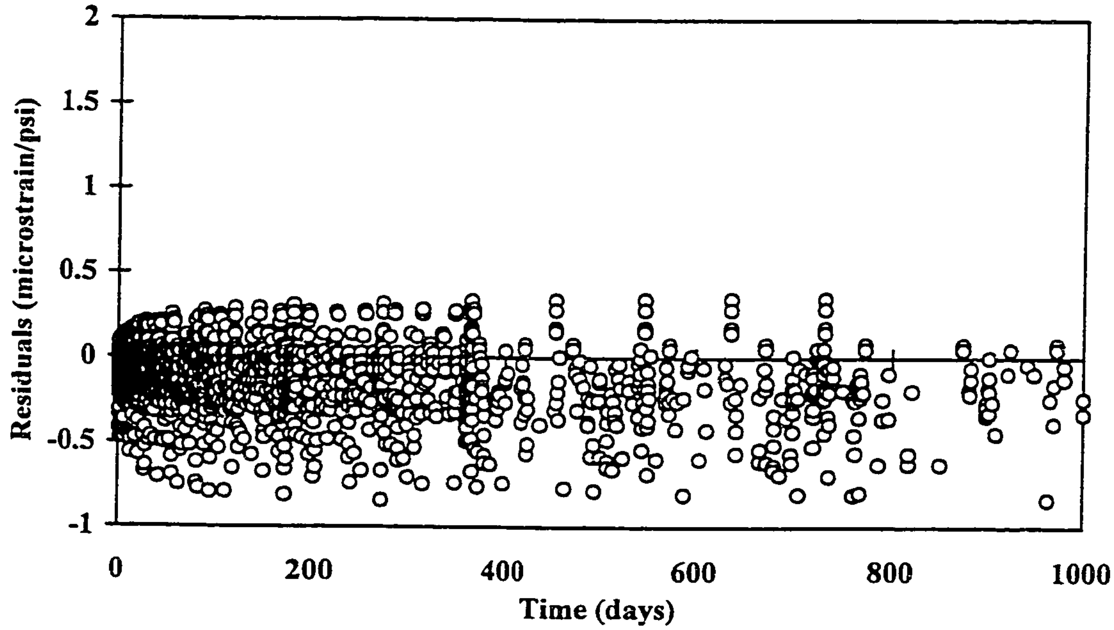


Figure 4.22: Creep compliance residuals for the ACI 209 model for short term duration (i.e. 0-1000 days)

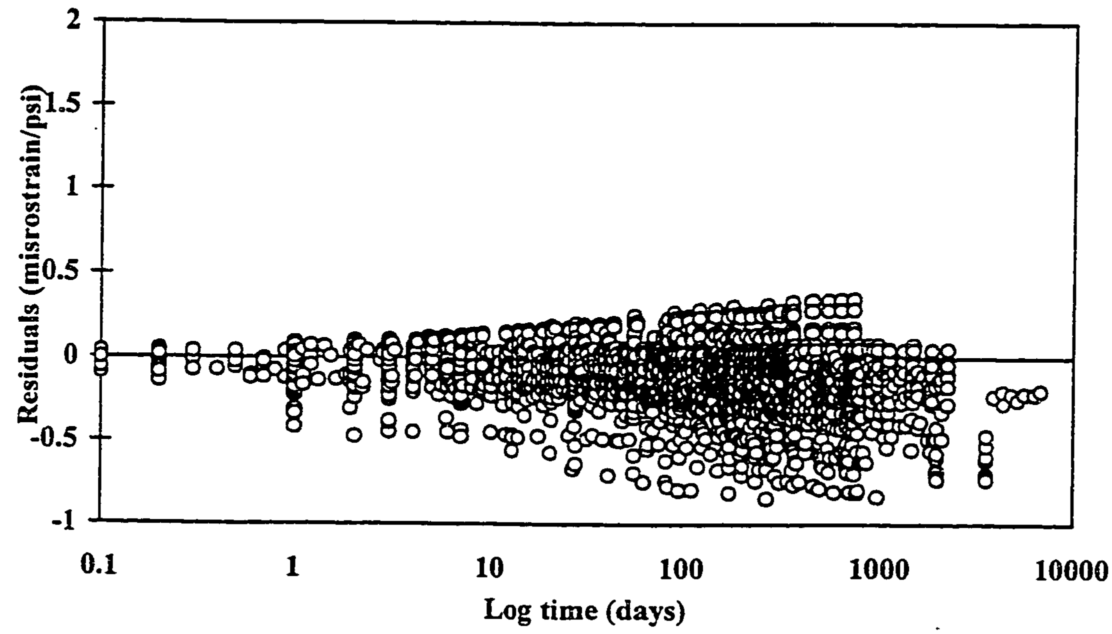


Figure 4.23: Creep compliance residuals for the ACI 209 model for long term duration (i.e. 0-7000 days)

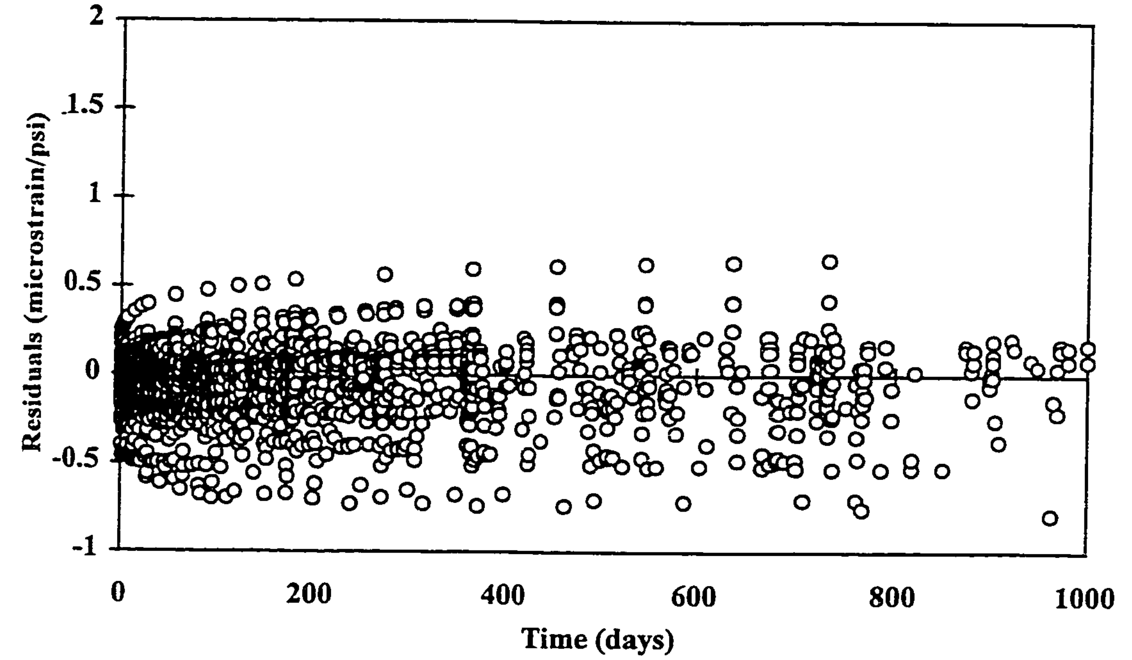


Figure 4.24: Creep compliance residuals for the B3 model for short term duration (i.e. 0-1000 days)

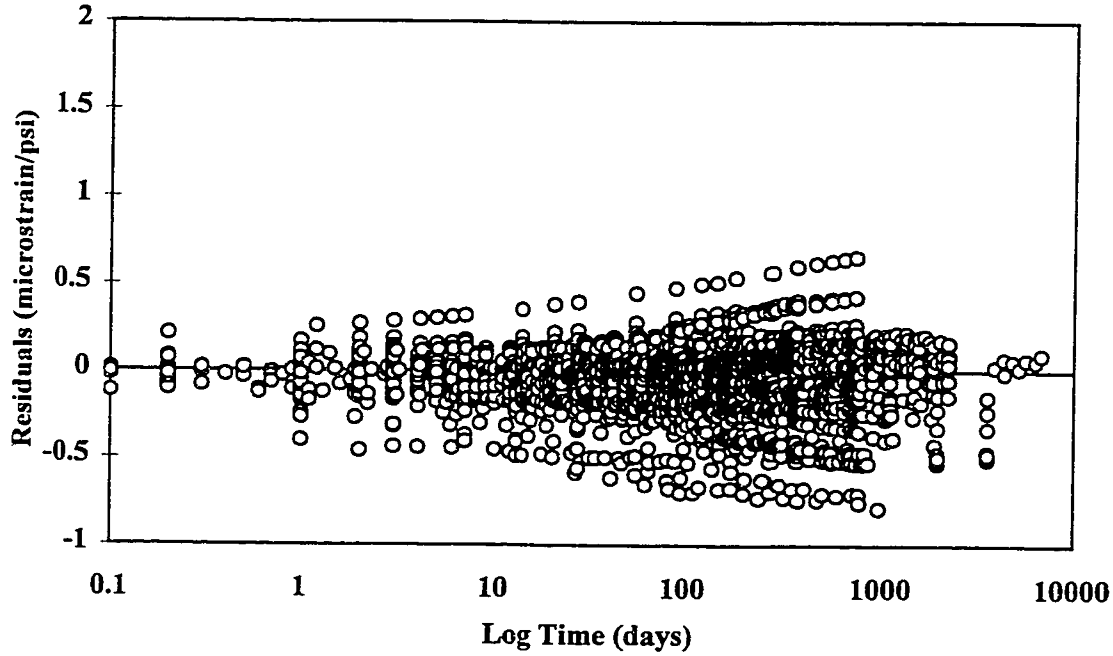


Figure 4.25: Creep compliance residuals for the B3 model for long term duration (i.e. 0-7000 days)

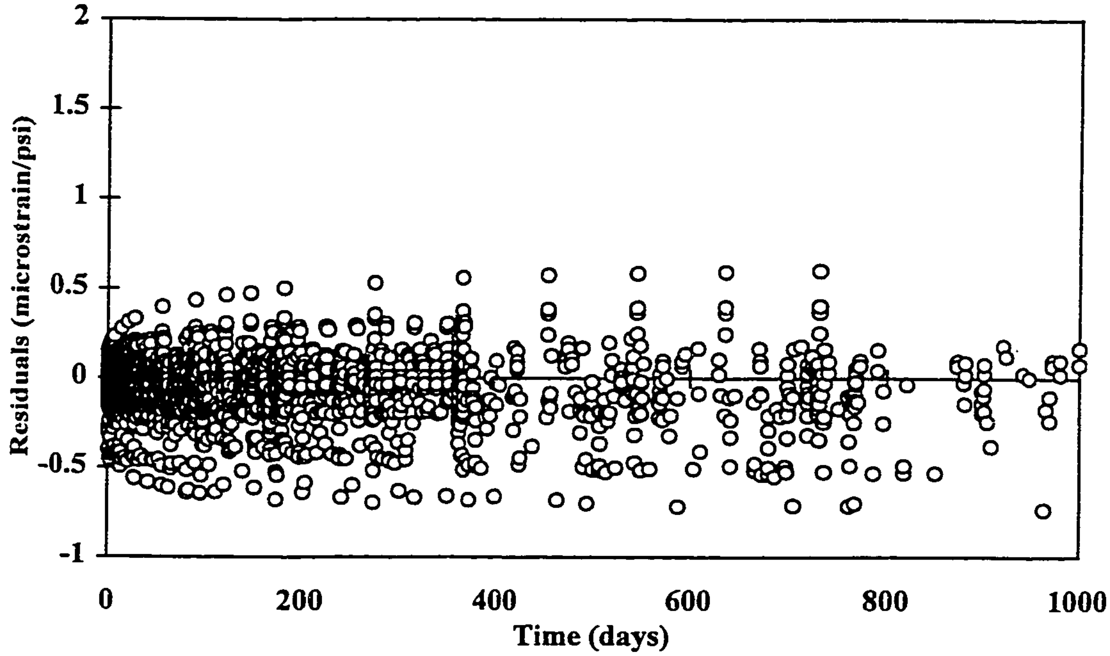


Figure 4.26: Creep compliance residuals for the CEB 90 model for short term duration (i.e. 0-1000 days)

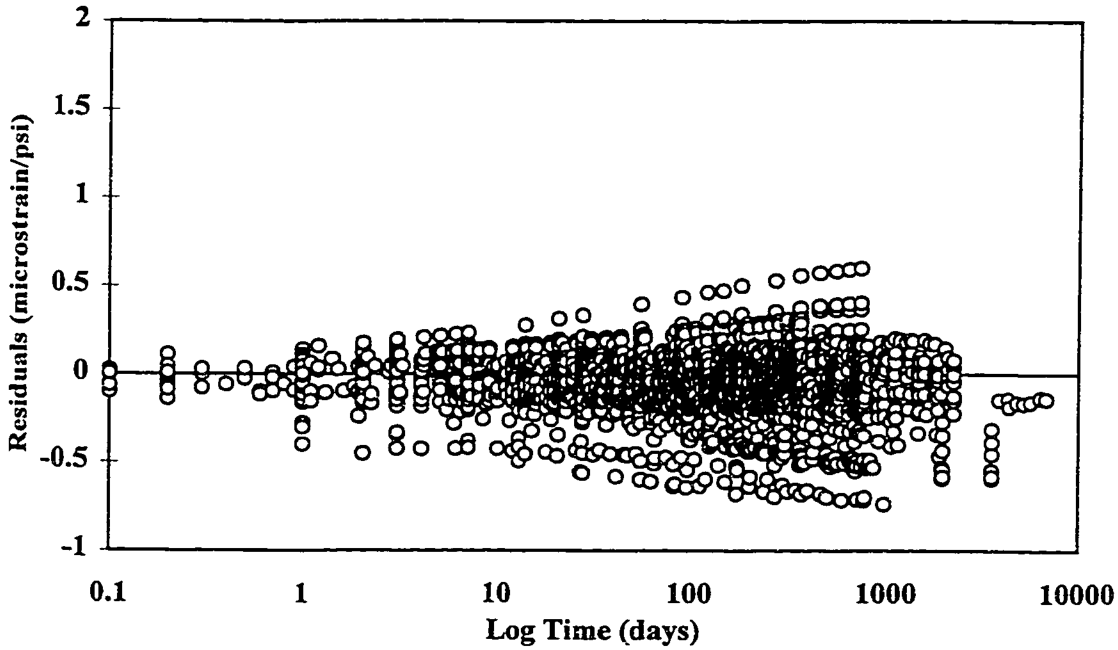


Figure 4.27: Creep compliance residuals for the CEB 90 model for long term duration (i.e. 0-7000 days)

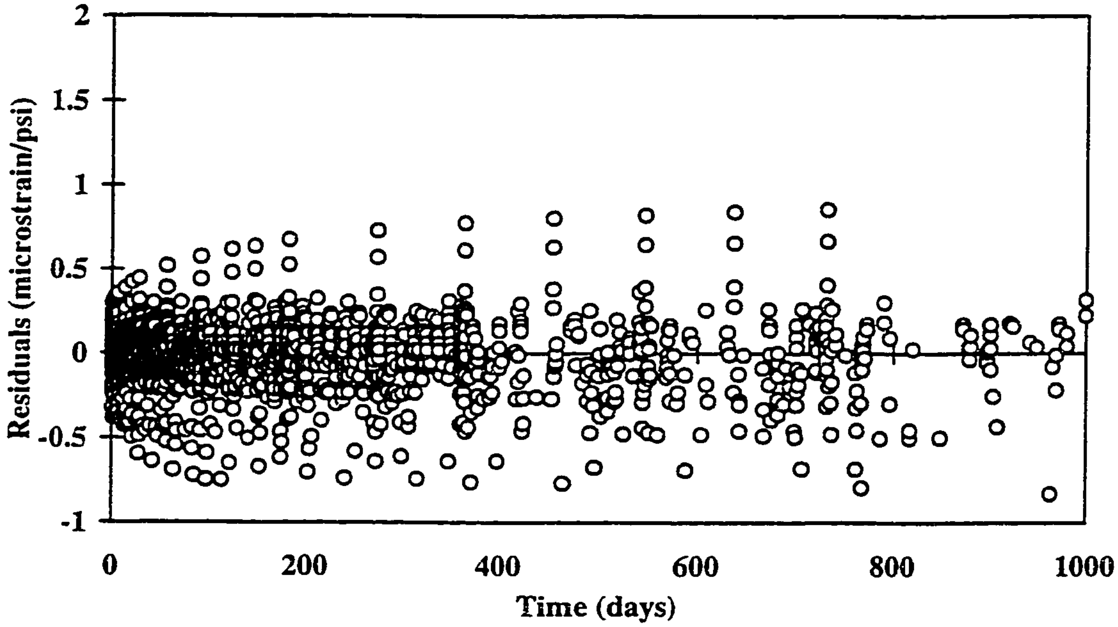


Figure 4.28: Creep compliance residuals for the GZ model for short term duration (i.e. 0-1000 days)

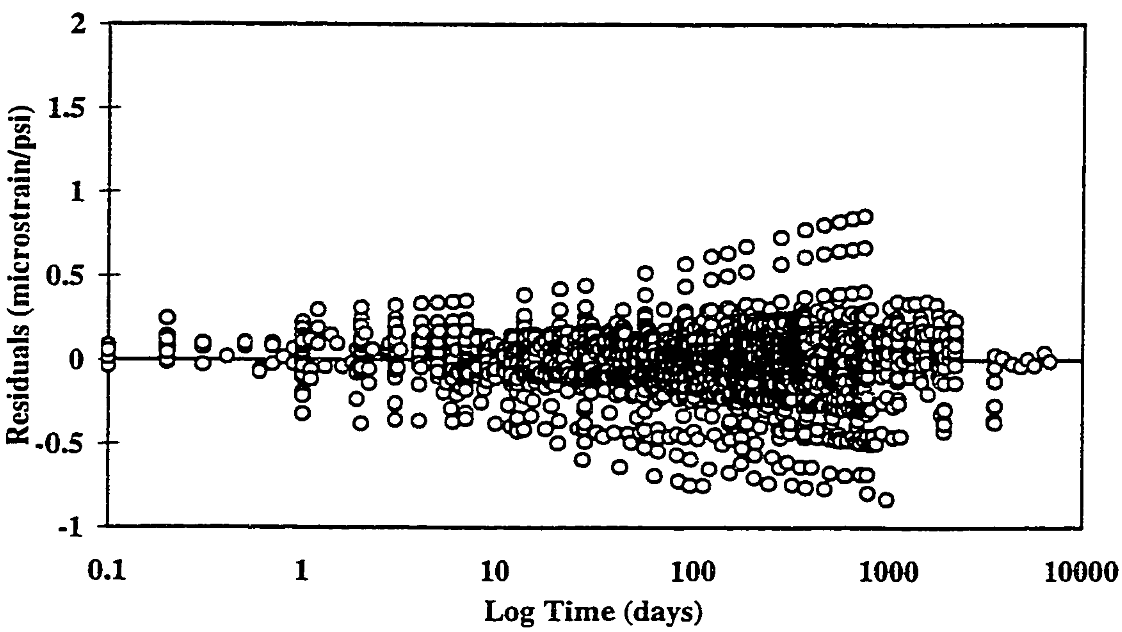


Figure 4.29: Creep compliance residuals for the GZ model for long term duration (i.e. 0-7000 days)

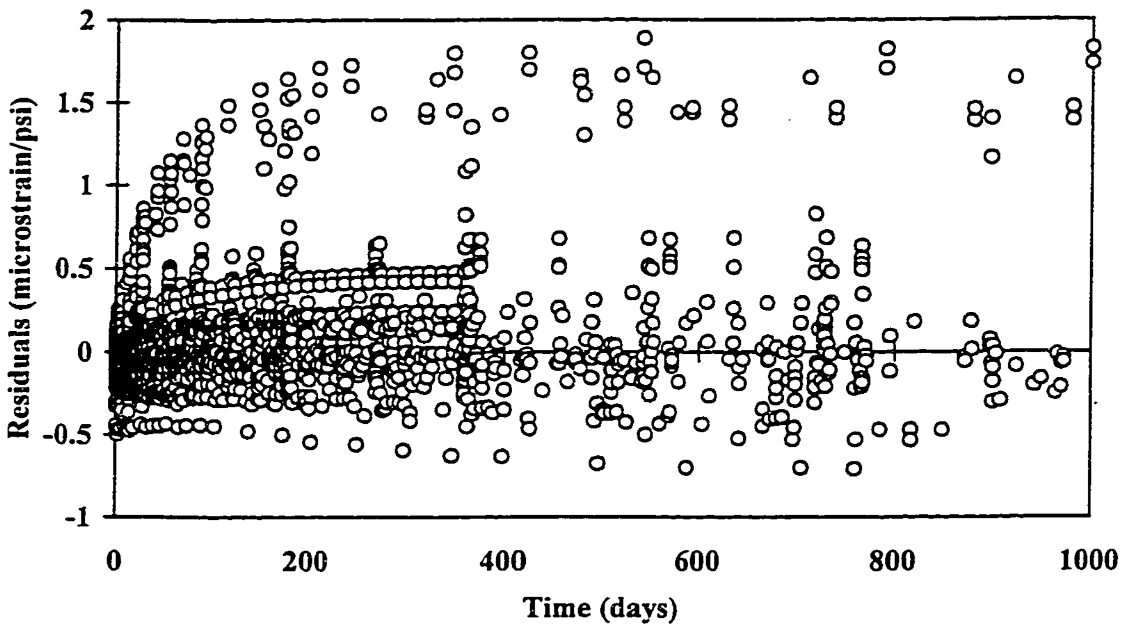


Figure 4.30: Creep compliance residuals for the SAK model for short term duration (i.e. 0-1000 days)

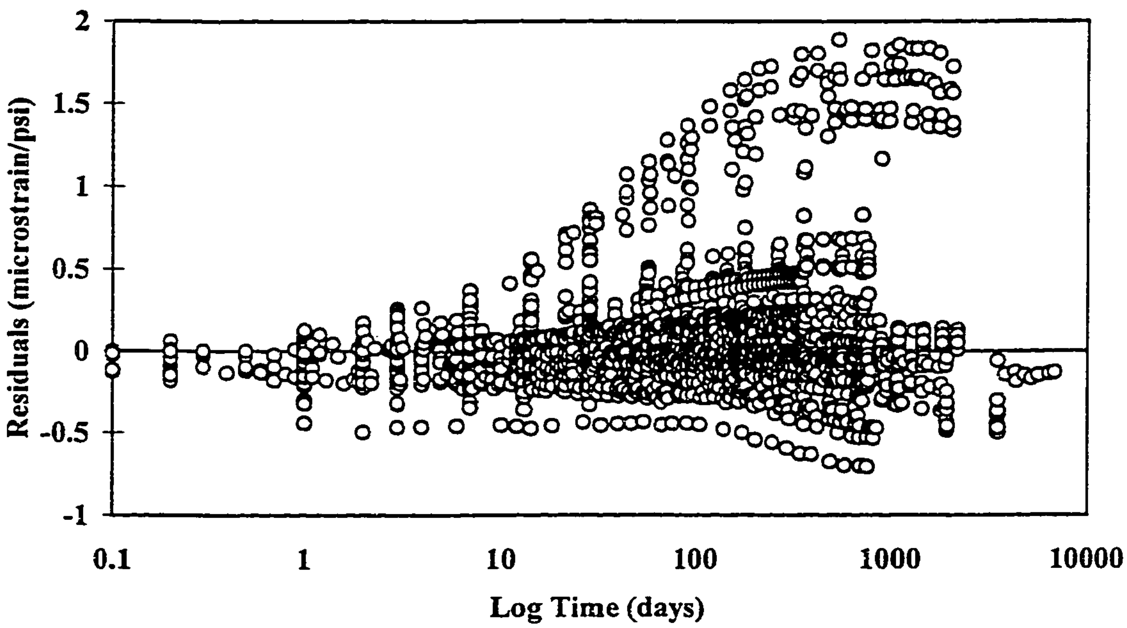


Figure 4.31: Creep compliance residuals for the SAK model for long term duration (i.e. 0-7000 days)

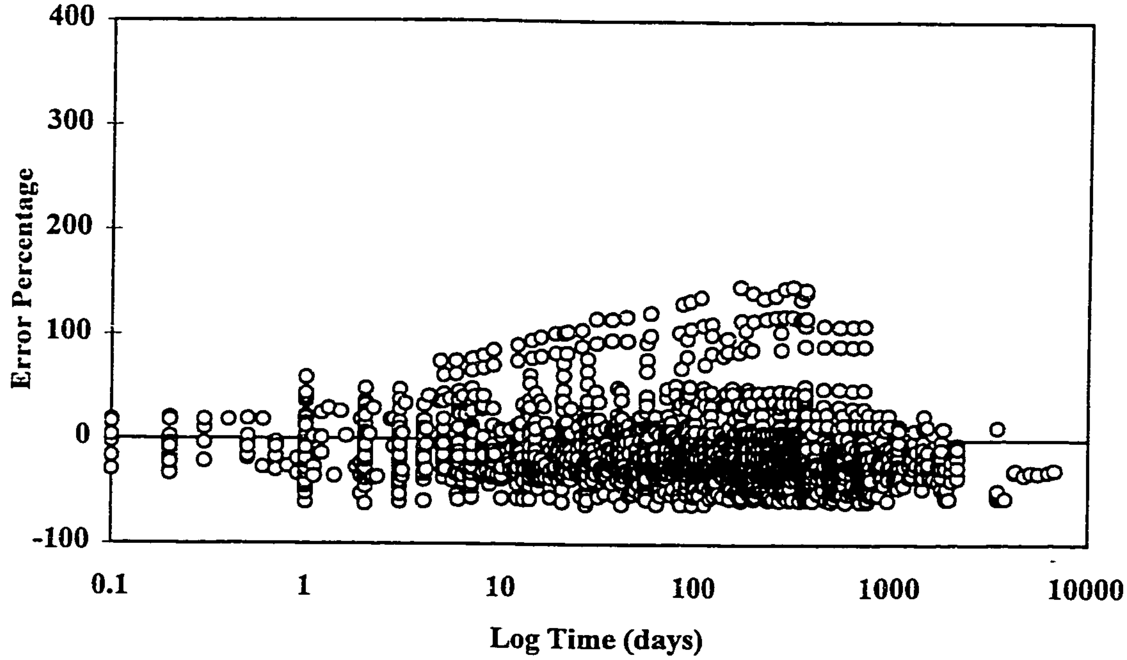


Figure 4.32 Creep compliance error percentage for the ACI 209 model for long term duration (i.e. 0-7000 days)

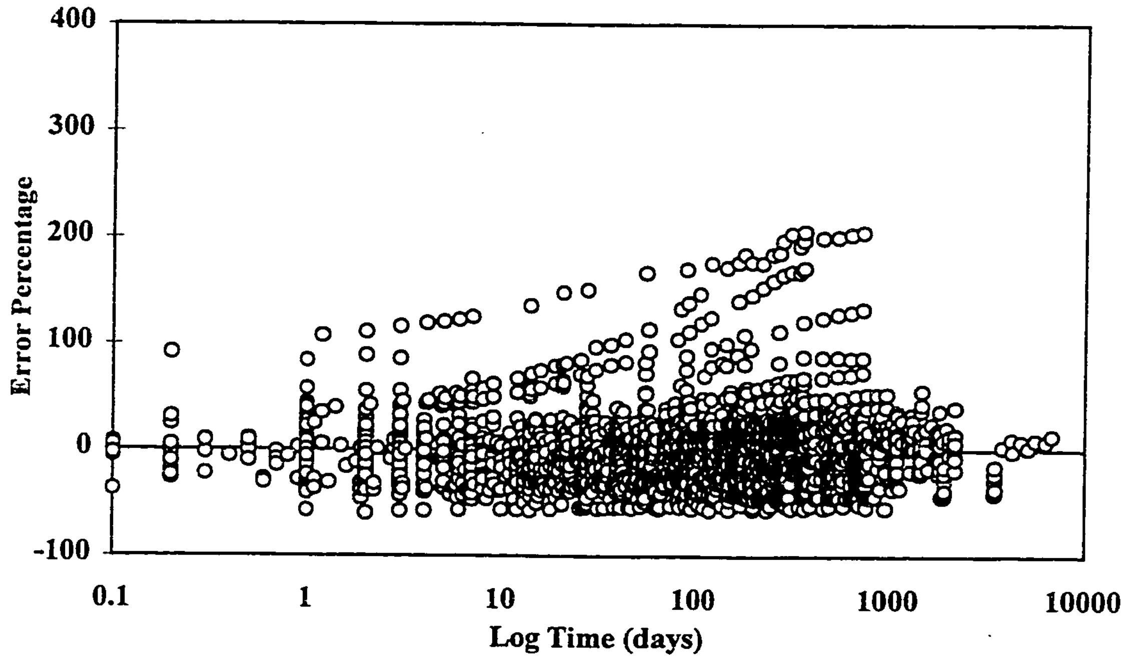


Figure 4.33 Creep compliance error percentage for the B3 model for long term duration (i.e. 0-7000 days)

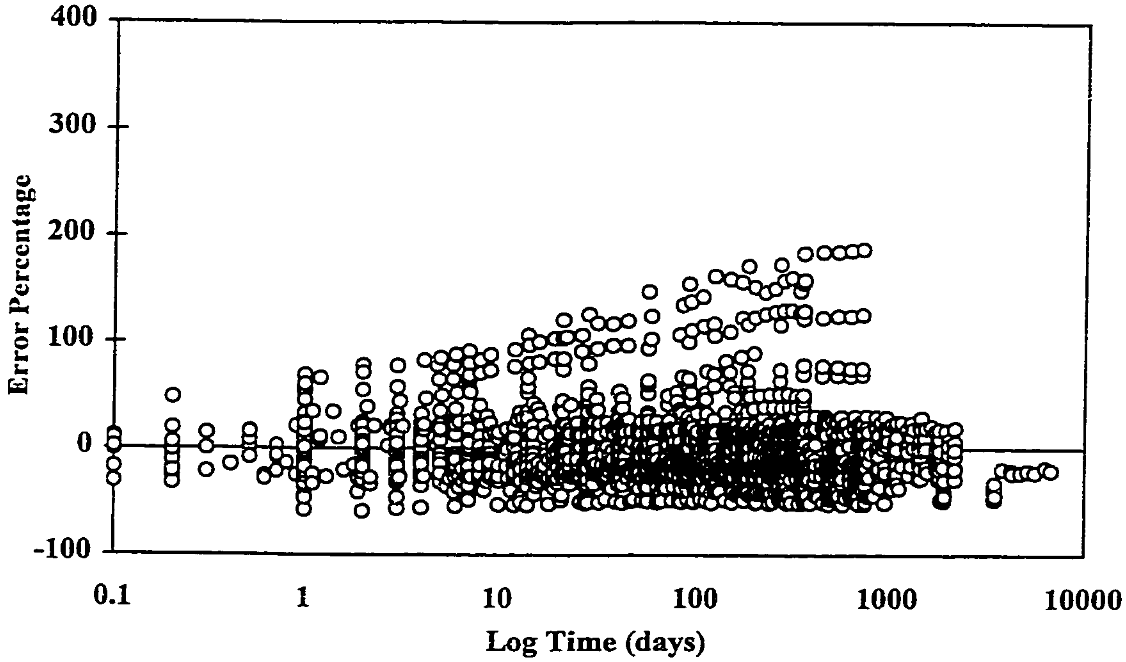


Figure 4.34 Creep compliance error percentage for the CEB 90 model for long term duration (i.e. 0-7000 days)

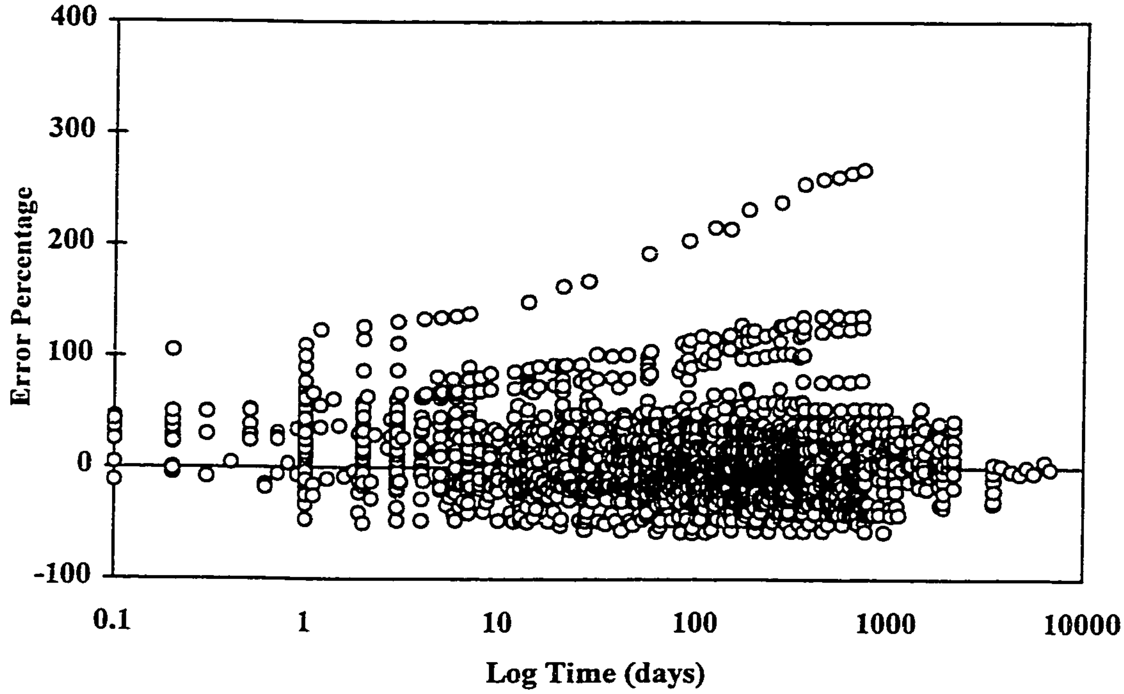


Figure 4.35 Creep compliance error percentage for the GZ model for long term duration (i.e. 0-7000 days)

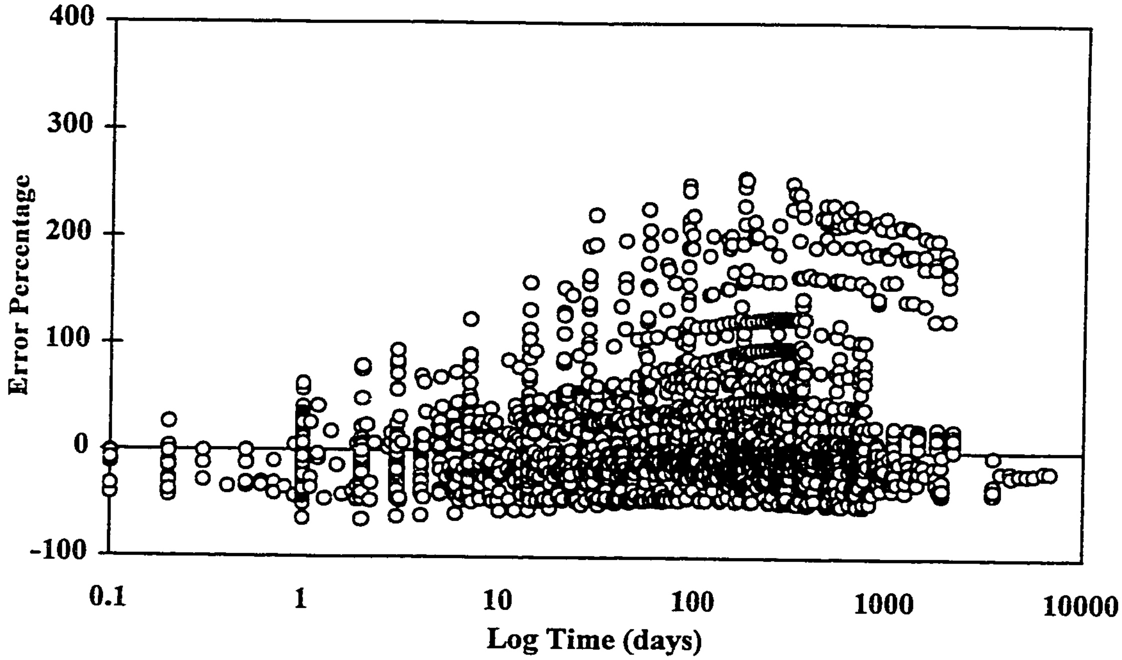


Figure 4.36 Creep compliance error percentage for the SAK model for long term duration (i.e. 0-7000 days)

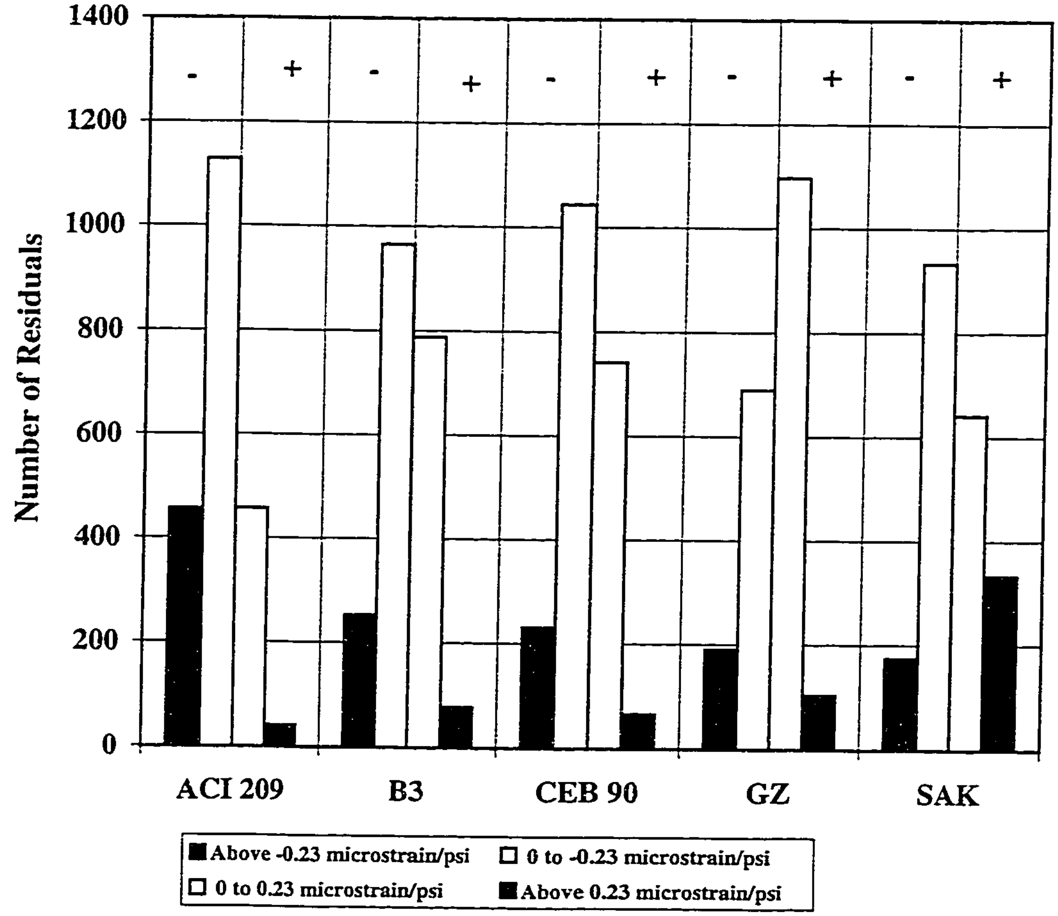


Figure 4.37: Distribution of residual points for creep compliance for 0-1000 days grouped into various residual ranges

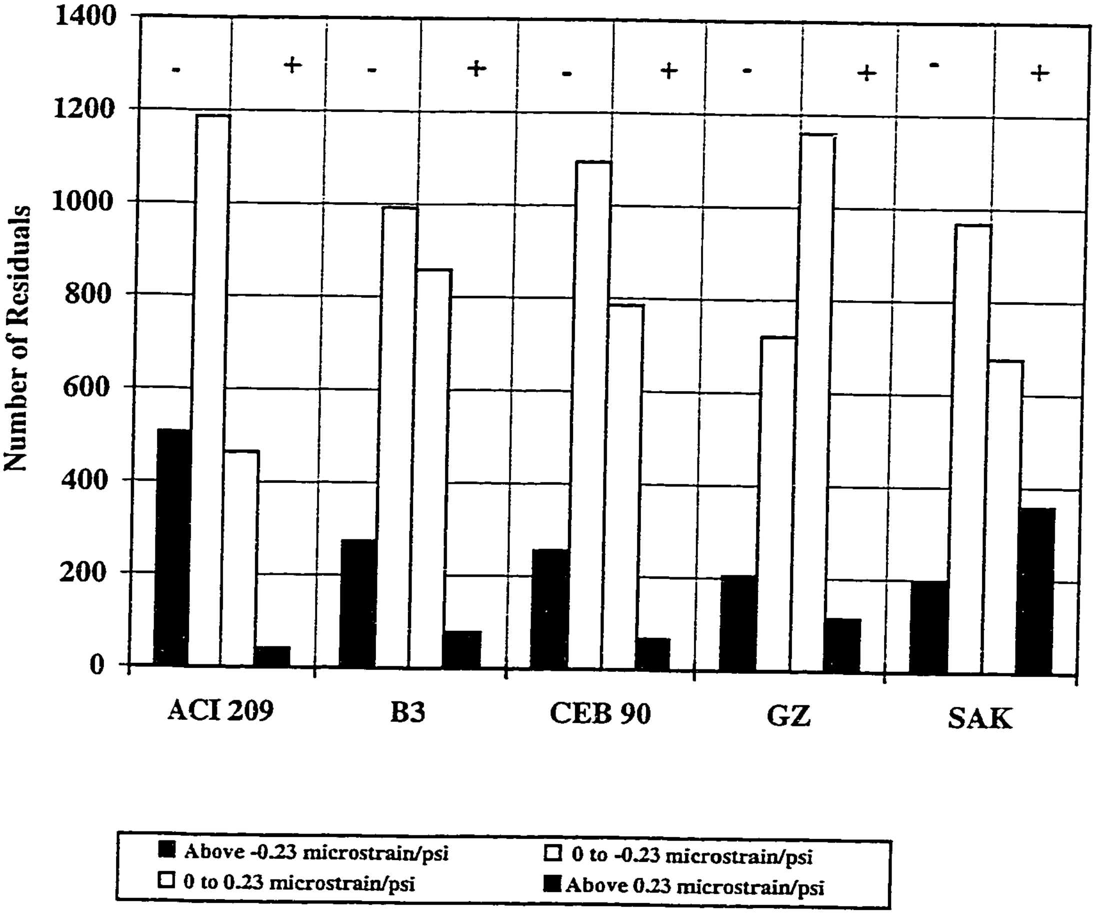


Figure 4.38: Distribution of residual points for creep compliance for 0-7000 days grouped into various residual ranges

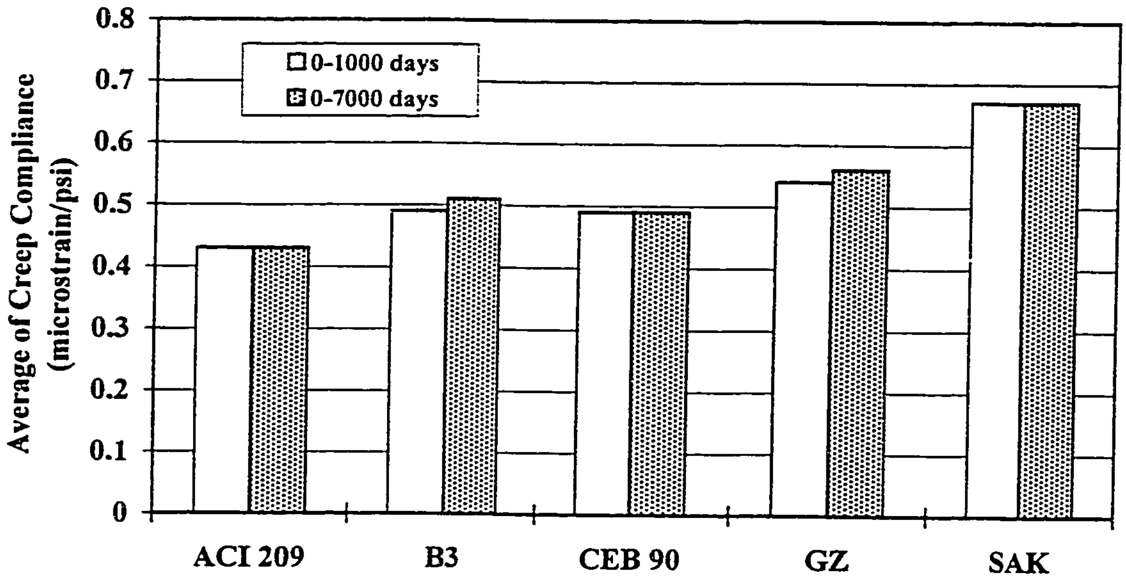


Figure 4.39: Average of creep compliance for five models for short (i.e. 0-1000 days) and long (i.e.0-7000 days) term duration

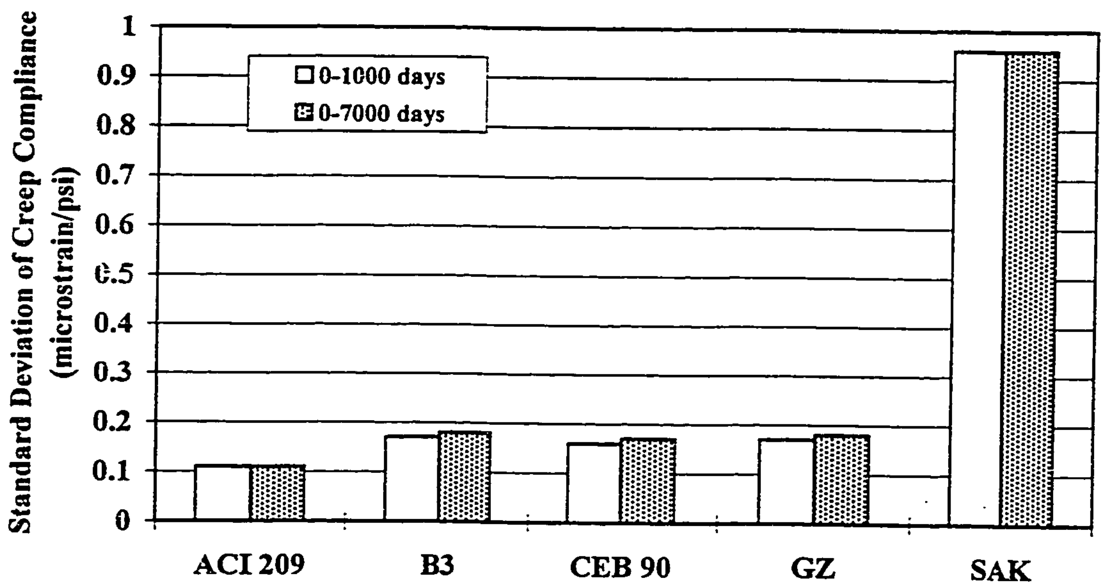


Figure 4.40: Standard deviation of creep compliance for five models for short (i.e. 0-1000 days) and long (i.e.0-7000 days) term duration

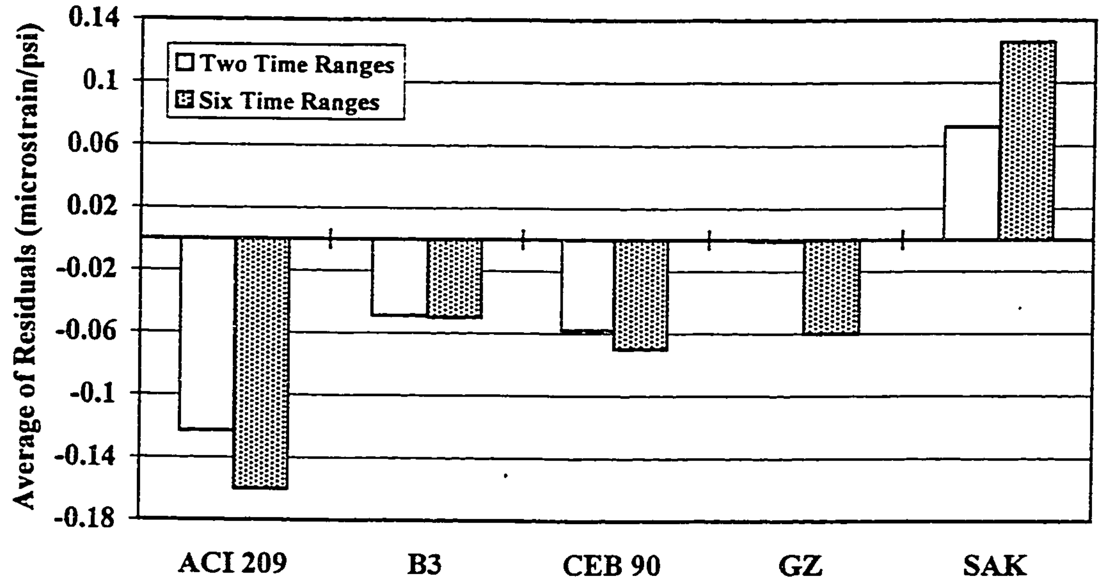


Figure 4.41: Average of creep compliance residuals for five models grouped into two and six time ranges

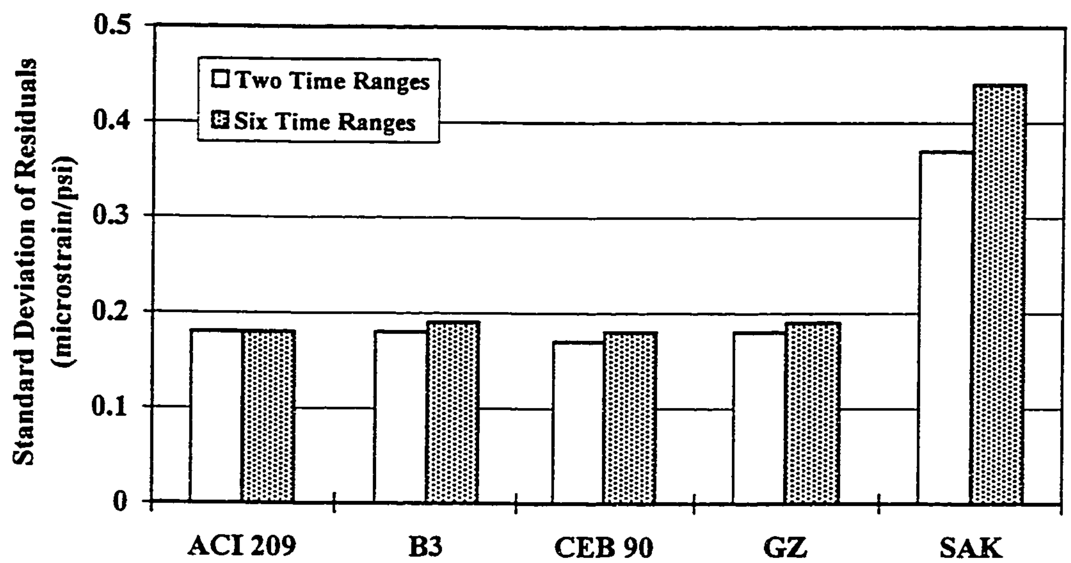


Figure 4.42: Standard deviation of creep compliance residuals for five mode grouped into two and six time ranges

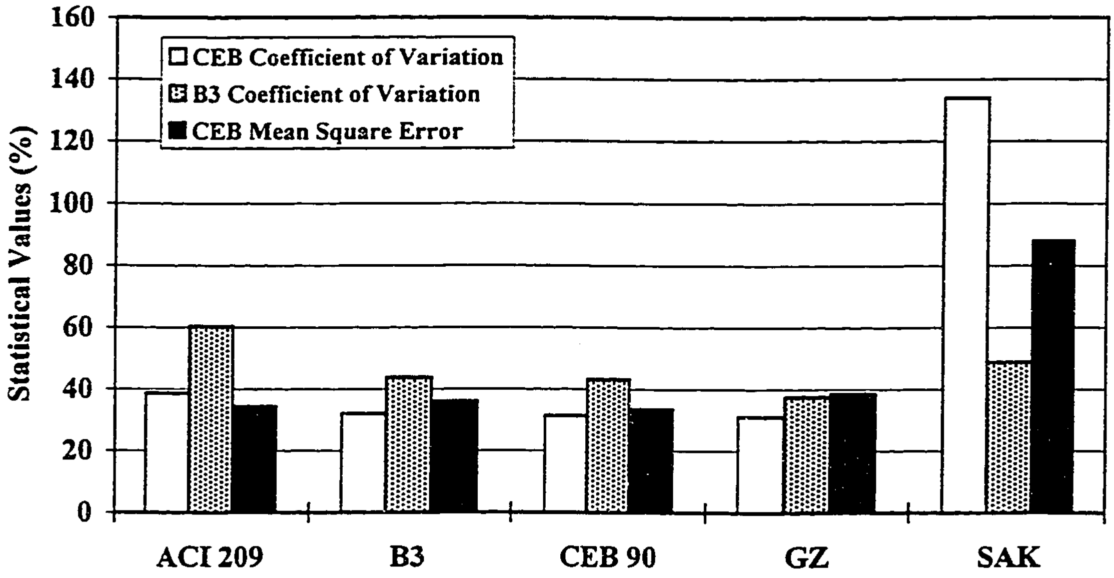


Figure 4.43: Coefficient of variation and mean square error for five models for creep compliance

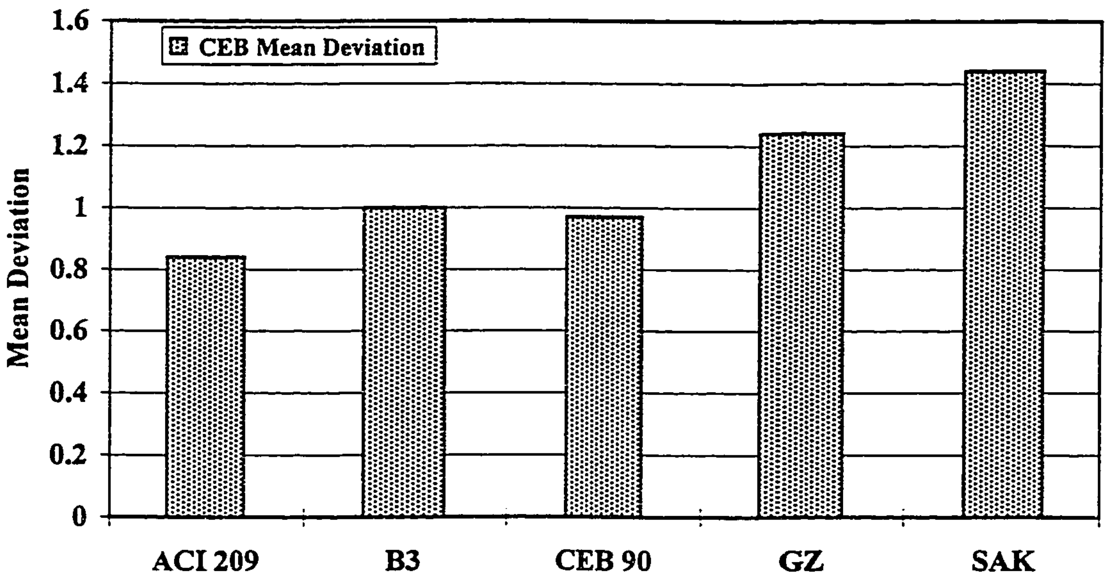


Figure 4.44: Mean deviation for five models for creep compliance

Chapter 5

Conclusions and Recommendations for Future Research

5.1 Conclusions

Five different shrinkage and creep models, including two code models were compared with the RILEM experimental data bank to determine the level of their accuracy. The models under investigation were the ACI 209 code model, the B3 model, the CEB 90 code model, the GZ model and the SAK model. The predicted creep and shrinkage strains from each model were evaluated by the residual method, the average and standard deviation methods, the coefficient of variation method, the mean square error method and the mean deviation method. Each model is rated on its performance for a given statistical method. A model receiving a rating as first or second in a given statistical method is considered to perform best in that category and earns one point. The sum of ratings in all categories is used as an indicator for evaluating the best model. The following conclusions are made from the results of this study.

1. The B3 model and the GZ model performed best for predicting shrinkage strain. A rating of 10/10 was received by the GZ model followed by the B3 model with a rating of 9/10. The ACI 209, CEB 90 and the SAK models received a rating of 2/10, 2/10, and 0/10 respectively. It is interesting to note that the CEB 90 code model

and the B3 model was calibrated to the RILEM experimental data bank, whereas the GZ model was formulated without the use of data bank and have performed exceptionally well.

2. The CEB 90 code model followed by the B3 model performed best for creep strain. The CEB 90 code model received a rating of 11/12 while the B3 model received a rating of 8/12. The GZ, ACI 209 and the SAK models received a rating of 7/12, 5/12, and 1/12 respectively.

3. The residual method combined with the average and standard deviation for the short (i.e. 0-1000 days) and long (i.e. 0-7000 days) time duration provided similar results as if six different time durations (i.e. 0-10 days, 10-100 days, 100 days-1year, 1-2 years, 2-3 years and above 3 years) were utilized using the same statistical approaches.

4. The range of residuals for shrinkage strains for all models varied from +900 to –500 microstrain and for creep compliance varied from +2.0 to –0.9 microstrain/psi.

5. The error percentage for shrinkage strain for all models, using a time duration of 0-7000 days, varied from +1500% to –100% whereas for creep compliance varied from +400% to –65%. Higher error percentages were observed during the first ten days of shrinkage due to the low experimental shrinkage strain values. For shrinkage

measured between 10-7000 days the error percentage for all five models varied from +750% to –65%.

6. The distribution of shrinkage strain residuals for all models is summarized in Table 5.1.

Table 5.1: Results of Distribution of Shrinkage Strain Residuals for Five Models

Model Name	Distribution of all Residual Points		Distribution of Residual Points in the Range Outside ± 100 microstrain		
	Overestimate data	Underestimate data	Overestimate data	Underestimate data	Total
ACI 209	60%	40%	29%	14%	43%
B3	36%	64%	**8%***	**25%***	**33%***
CEB 90	39%	61%	7%	32%	39%
GZ	**43%***	**57%***	13%	25%	38%
SAK	94%	6%	76%	2%	78%

Note: * indicates best performance

It can be observed from the table that the distribution of all residual points for the GZ model is more balanced when compared to the other four models. The ACI 209 and the SAK models are an overestimating shrinkage models whereas the other three models are an underestimating shrinkage models. The distribution of residual points in the range outside ± 100 microstrain was the lowest for the B3 model followed by the GZ and the CEB 90 models.

7. The distribution of residuals for creep compliance is summarized in Table 5.2.

Table 5.2: Results of Distribution of Creep Compliance Residuals for Five Models

Model Name	Distribution of all Residual Points		Distribution of Residual Points in the Range Outside ± 0.23 microstrain/psi		
	Overestimate data	Underestimate data	Overestimate data	Underestimate data	Total
ACI 209	23%	77%	2%	23%	25%
B3	42%	58%	4%	12%	16%
CEB 90	39%	61%	3%	11%	**14%***
GZ	58%	42%	5%	9%	**14%***
SAK	**47%***	**53%***	16%	9%	25%

Note: * indicates best performance

It can be observed from the table that the distribution of all residual points for the SAK model is more balanced among the five models. The distribution of residual points in the range outside ± 0.23 microstrain/psi (i.e. ±25% of total distribution of residuals) is lowest for the CEB 90 code model and the GZ model followed by the B3 model.

8. Results of the average and standard deviation are summarized in Table 5.3.

Table 5.3: Results of the Average and Standard Deviation for Five Models

Mean Average	Time Range	ACI 209	B3	CEB 90	GZ	SAK
Shrinkage Strain Residuals in microstrain	2	43	**−29***	−54	−33	229
	6	27	−27	−55	**−19***	233
Creep Compliance in microstrain/psi	2	**0.43***	0.50	0.49	0.55	0.67
Creep Compliance Residuals in microstrain/psi	2	−0.12	−0.050	−0.051	**−0.001***	0.072
	6	−0.16	−0.05	−0.05	**−0.004***	0.13
Mean Standard Deviation	**Time Range**	**ACI 209**	**B3**	**CEB 90**	**GZ**	**SAK**
Shrinkage Strain Residuals in microstrain	2	163	**117***	137	124	183
	6	146	**107***	121	114	153
Creep Compliance in microstrain/psi	2	**0.11***	0.18	0.17	0.18	0.96
Creep Compliance Residuals in microstrain/psi	2	0.18	0.19	**0.17***	0.19	0.37
	6	**0.18***	0.19	**0.18***	0.19	0.44

Note : * indicates best performance

It can be observed from the table that the B3 model performed best for mean average and mean standard deviation of shrinkage strain residual followed by the GZ model. For the mean average of creep compliance and compliance residuals the GZ model and the ACI 209 code model performed best. For the mean standard deviation of creep compliance and compliance residuals the ACI 209 code model and the CEB 90 code model performed best.

9. Results of the B3 coefficient of variation (ω_{B3}) method are summarized in Table 5.4.

Table 5.4: Results of the B3 Coefficient of Variation (ω_{B3}) for Five Models

Category	ACI 209	B3	CEB 90	GZ	SAK
Shrinkage Strain	46%	**44%***	49.2%	44.6%	55%
Creep Compliance	60.3%	43.4%	43.3%	**37.5%***	48.8%

Note: * indicates best performance

It can be observed from the table that the B3 model and the GZ model followed by the ACI 209 code model performed best for shrinkage strain, whereas the GZ model followed by the B3 model and the CEB 90 code model performed best for creep compliance.

10. Results of the CEB mean coefficient of variation (V_{CEB}) are summarized in Table 5.5.

Table 5.5: Results of the CEB Mean Coefficient of Variation (V_{CEB}) for Five Models

Category	ACI 209	B3	CEB 90	GZ	SAK
Shrinkage Strain	43%	**31%***	36%	32%	81%
Creep Compliance	38.6%	32%	**31%***	**31%***	134%

Note: * indicates best performance

It can be observed from the table that the B3 model followed by the GZ model performed best for shrinkage strain, whereas the CEB 90 code model and the GZ model followed by the B3 model performed best for creep compliance.

11. Results of the CEB mean square error (F_{CEB}) are summarized in Table 5.6.

Table 5.6: Results of the CEB Mean Square Error (F_{CEB}) for Five Models

Category	ACI 209	B3	CEB 90	GZ	SAK
Shrinkage Strain	112%	76%	76%	**50%***	247%
Creep Compliance	34.4%	36%	**33.5%***	38.6%	88%

Note: * indicates best performance

It can be observed from the table that the GZ model followed by the B3 model and the CEB 90 code model performed best for shrinkage strain, whereas the CEB 90 code model followed by the ACI 209 code model performed best for creep compliance.

12. Results of the CEB mean deviation (M_{CEB}) are summarized in Table 5.7.

Table 5.7: Results of the CEB Mean Deviation (M_{CEB}) for Five Models

Category	ACI 209	B3	CEB 90	GZ	SAK
Shrinkage Strain	1.30	1.11	1.12	**1.02***	2.2
Creep Compliance	0.84	**1.0***	0.97	1.10	1.24

Note: * indicates best performance

It can be observed from the table that the GZ model followed by the B3 model and the CEB 90 code model performed best for shrinkage strain, whereas the B3 model followed by the CEB 90 code model performed best for creep compliance.

13. The different statistical methods to evaluate the models using the RILEM data bank should not be the only way to judge the validity of a given model. Other consideration such as simplicity, correct physical phenomena representations and structural safety should be taken into account to make the final decision when selecting a valid model.

5.2 Recommendations for Future Research

In this study, the performance of shrinkage and creep models for different creep duration or drying durations have been evaluated. Further studies based on various type of concrete mix design parameters, different effective thicknesses of members and various relative humidities should be conducted. Further, a creep prediction model for a nonlinear type analysis should be developed. This type of model is possible by utilizing a finite element approach where local stresses, local cracking and non-uniform moisture distribution can be taken into account.

It is recommended that, when modeling creep or shrinkage, the models should be based on realistic physical phenomena describing acceptable trends. Moreover, the models should perform well using the statistical methods described in this study. The RILEM experimental data bank should be evaluated for the accuracy of the data sets and the data sets with incomplete information should be isolated.

APPENDIX I: Summary of Equations Describing Shrinkage and Creep Models

I.1 The ACI 209 Code Model

I.1.1 Calculate Compressive Strength:

$$f_c'(t_o) = f_c'_{(28)}\,(t_o / (b + c\,t_o))$$

Type of cement	Moist cured concrete		Steam cured concrete	
I	b = 4	c = 0.85	b = 1	c = 0.95
III	b = 2.30	c = 0.92	b = 0.70	c = 0.98

I.1.2 Calculate Modulus of Elasticity:

$$E_{cmto} = 33(\gamma)^{3/2}\,(f_c'(t_o))^{1/2}$$

I.1.3 Calculate Shrinkage Strain:

$$\varepsilon_s(t) = \frac{t_s}{b + t_s}\,K_{SS}\,K_{SH}\,\varepsilon_{shu}$$

Humidity	Moist cured concrete	Steam cured concrete
$40\% \leq H \leq 80\%$	$b = 35 \quad t \geq 7$ days $K_{SH} = 1.40 - 0.01H$	$b = 55 \quad t \geq 1$ to 3 days $K_{SH} = 1.40 - 0.01H$
$80\% \leq H \leq 100\%$	$b = 35 \quad t \geq 7$ days $K_{SH} = 3 - 0.03H$	$b = 55 \quad t \geq 1$ to 3 days $K_{SH} = 3 - 0.03H$

$K_{SS} = 1.14 - 0.09(V/S)$

$\varepsilon_{shu} = 780 \times 10^{-6}$ in./in. (Same for both moist and steam cured concrete)

I.1.4 Calculate Creep Strain:

$$\text{Creep strain} = \frac{\sigma}{E_{cmto}}\,C_c(t)$$

$$C_c(t) = \frac{t^{0.60}}{10 + t^{0.60}} C_{cu} K_{CH} K_{CA} K_{CS}$$

$$C_{cu} = 2.35$$

Moist cured concrete	**Steam cured concrete**
$t, t_o \geq 7$ days, $H \geq 40\%$ $K_{CA} = 1.25\,(t_o)^{-0.118}$	$t, t_o \geq 1$ to 3 days, $H \geq 40\%$ $K_{CA} = 1.13\,(t_o)^{-0.095}$
$K_{CH} = 1.27 - 0.0067H$ $K_{CS} = 1.14 - 0.09(V/S)$	$K_{CH} = 1.27 - 0.0067H$ $K_{CS} = 1.14 - 0.09(V/S)$

I.1.5 Calculate Total Strain:

$$\varepsilon(t) = \varepsilon_s(t) + \frac{\sigma}{E_{cmto}} (1 + C_c(t))$$

I.1.6 Calculate of Compliance Function:

$$\text{Compliance function} = \frac{(1 + C_c(t))}{E_{cmto}}$$

I.2 The B3 Model

I.2.1 Calculate Mean Concrete Compressive Strength:

If experimental mean concrete compressive strength is not available

$$f'_c = f_{ck} + 1200$$

I.2.2 Calculate Shrinkage Strain:

Mean shrinkage strain in cross section

$$\varepsilon_{sh}(t, t_o) = \varepsilon_{sh\infty} K_h S(t)$$

I.2.2.1 Ultimate Shrinkage Strain:

$$\varepsilon_{sh\infty} = -\alpha_1\,\alpha_2(\,26\,(w)^{2.1}\,(f'_c)^{-0.28}\ + 270\,)\quad x\quad 10^{-6}$$

Type of cement	α_1
I	1.0
II	0.85
III	1.1

Type of curing	α_2
Steam cured	0.75
Water cured or h = 100%	1.0
Sealed during curing	1.2

I.2.2.2 Time Dependence:

$$S\,(t)\ = \tanh\ \sqrt{\frac{t - t_o}{T_{sh}}}$$

$$S\,(t')\ = \tanh\ \sqrt{\frac{t' - t_o}{T_{sh}}}$$

$$T_{sh}\ = K_t\ (K_s\,D)^2$$

$$K_t\ = 190.8\ (t_o)^{-0.08}\,(f'_c)^{-0.25}$$

Type of member or structure	K_s
for an infinite slab	1.00
for an infinite cylinder	1.15
for an infinite square prism	1.25
for a sphere	1.30
for a cube	1.55

K_s can be assumed to be 1 if type of member is not defined

I.2.2.3 Humidity Dependence:

Humidity (h)	K_h
$h \leq 0.98$	$1 - h^3$
$h = 1$	-0.2
$0.98 \leq h \leq 1$	linear interpolation

I.2.3 Calculate Creep Strain:

I.2.3.1 Compliance Function:

$$j(t, t') = q_1 + C_o(t, t') + C_d(t, t', t_o)$$

$$q_1 = \frac{0.6 \times 10^6}{E_{28}}$$

$$E_{28} = 57000\ (f'_c)^{1/2}$$

I.2.3.2 Basic Creep:

$$C_o(t, t') = q_2 Q(t, t') + q_3 \ln(1 + (t - t')^n) + q_4 \ln(t / t')$$

$$Q(t, t') = Q_f(t') \left[1 + \frac{(Q_f(t'))^{r(t')}}{Z(t,t')^{r(t')}} \right]^{-1/r(t')}$$

$$Q_f(t') = [\,0.086\,(t')^{2/9} + 1.21\,(t')^{4/9}]^{-1}$$

$$Z(t,t') = (t')^{-m} \ln(1+(t - t')^n)$$

$$m = 0.5, \quad n = 0.1$$

$$r(t') = 1.7\,(t')^{0.12} + 8$$

$$q_2 = 451.1\,(c)^{0.5}\,(f'_c)^{-0.9}$$

$$q_3 = 0.29\,(w/c)^4\,q_2$$

$$q_4 = 0.14\,(a/c)^{-0.7}$$

I.2.3.3 Drying Creep:

$$C_d(t, t', t_o) = q_5 [\exp\{-8H(t)\} - \exp\{-8H(t')\}]^{1/2} \qquad \text{for } t' \geq t_o$$

$$H(t) = 1 - (1-h)\, S(t)$$

$$H(t') = 1 - (1-h)\, S(t')$$

$$q_5 = 7.57 \times 10^5 (f'_c)^{-1} \; ABS(\varepsilon_{sh\infty})^{-0.6}$$

I.2.4 Calculate Total Strain:

$$\varepsilon(t) = J(t,t')\, \sigma + \varepsilon_{sh}(t)$$

I.3 The CEB 90 Code Model

I.3.1 Calculate Mean Concrete Strength:

$$f_{cm} = f'_{c28} + 1200$$

I.3.2 Calculate Tangent Modulus of Elasticity:

$$E_c = (E_{co})(f_{cm} / 1450)^{1/3}$$

$$E_{co} = 3117500 \text{ psi}$$

I.3.3 Calculate Modulus of Elasticity at Age t_o:

$$E_c(t_o) = (E_c)\{\exp[0.5S\,(1 - (28/t_o)^{0.5})]\}$$

Type of cement	S
Slow hardening (SL)	0.38
Normal and rapid hardening (R)	0.25
Rapid hardening high strength (RS)	0.2

I.3.4 Calculate Shrinkage Strain:

$$\varepsilon_{cs}(t - t_s) = (\varepsilon_{cso})\, \beta_s(t - t_s)$$

$$\varepsilon_{cso} = \varepsilon_s(f_{cm})\, (\beta_{RH})$$

$$\varepsilon_s(f_{cm}) = [160 + 10\,\beta_{sc}\,(9 - f_{cm}/1450)] \times 10^{-6}$$

Type of Cement	β_{sc}
Slow hardening (SL)	4
Normal or rapid hardening (R)	5
Rapid hardening high strength (RS)	8

Humidity	β_{RH}
40 % $\leq$ RH $\leq$ 99 %, stored in air	$-1.55 \times \beta_{ARH}$
RH $\geq$ 99 %, immersed in water	0.25

$$\beta_{ARH} = 1 - (RH/100)^3$$

$$\beta_s(t-t_s) = \sqrt{\frac{(t - t_s)}{\{350(h_o/4)^2\} + (t-t_s)}}$$

I.3.5 Calculate Creep Strain:

$$\text{Creep strain} = \phi(t, t_o)\,\frac{\sigma}{E_c}$$

$$\phi(t, t_o) = (\phi_o)\,\beta_c(t-t_o)$$

$$\phi_o = \phi_{RH}\,\beta\,(f_{cm}) \times \beta(t_o)$$

$$\phi_{RH} = 1 + \frac{(1 - RH/100)}{0.46(h_o/4)^{1/3}}$$

$$\beta(f_{cm}) = 5.3\,/\,(f_{cm}/1450)^{1/2}$$

$$\beta\,(t_o) = (0.1 + t_o^{0.20})^{-1}$$

$$\beta_c(t-t_o) = \frac{(t - t_o)^{0.3}}{\{\beta_H + (t - t_o)\}^{0.3}}$$

$$\beta_H = 150\,[\,1 + (0.012RH)^{18}]\,(h_o/4) + 250 \leq 1500$$

I.3.6 Calculate Total Strain:

$$\varepsilon(t) = \varepsilon_{cs}(t-t_s) + \left[\frac{\phi(t, t_o)}{E_c} + \frac{1}{E_c(t_o)} \right] \sigma$$

I.3.7 Calculate Compliance Function:

$$\text{Compliance function} = \frac{\phi(t, t_o)}{E_c} + \frac{1}{E_c(t_o)}$$

I.4 The GZ Model

I.4.1 Calculate Mean Concrete Strength:

If experimental mean concrete compressive strength is not available

$$f_{cm28} = f_{ck28} + 1200$$

I.4.2 Calculate Mean Strength Based on Time:

If experimental concrete compressive strength at loading is not available

$$f_{cmto} = f_{cm28} \frac{t_o^{3/4}}{(a + b\,(t_o)^{3/4})}$$

Type of cement	a	b	K
I	2.8	0.77	1.0
II	3.4	0.72	0.7
III	1.0	0.92	1.33

I.4.3 Calculate Mean Modulus of Elasticity:

If experimental data is not available

$$E_{cmto} = 500000 + 52000\,(f_{cmto})^{1/2}$$

I.4.4 Calculate Mean Strength and Modulus of Elasticity Based on Time if Experimental Data on E_{c28} and f_{cm28} is Available:

From the following equation, using experimental E_{c28}, back calculate f_{cm28} and average it with the experimental f_{cm28} and get the $f_{cm28(average)}$

$$E_{c28} = 500000 + 52000\,(f_{cm28})^{1/2}$$

Then from the $f_{cm28(average)}$ calculate the f_{cmto}, f_{cmtc}, and $E_{cmto(average)}$ from the following equations.

$$f_{cmto(average)} = f_{cm28(average)} \frac{t_o^{\;3/4}}{(a + b\,(t_o)^{3/4})}$$

$$E_{cmto(average)} = 500000 + 52000\,(f_{cmto(average)})^{1/2}$$

I.4.5 Calculate Shrinkage Strain:

Shrinkage strain $= \varepsilon_{sh} = (\varepsilon_{shu})\,\beta(h)\,\beta(t)$

For h < 0.96	$\beta(h) = 1 - 1.18\,h^4$
For sealed specimens h = 0.96	$\beta(h) = 0$

$$\beta(t) = \frac{7.27 + \ln(t - t_c)}{17.18} \quad x \quad \frac{t - t_c}{t - t_c + 9.7(V/S)^2}$$

$$\varepsilon_{shu} = 857\;K \left[\frac{f_{cm28}}{f_{cmtc}}\right]^{1/2} \left[\frac{4000}{f_{cm28}}\right]^{1/2} x\;10^{-6}$$

I.4.6 Calculate Creep Strain:

Creep strain $=$ (stress / E_{cmto}) (1+Creep coefficient)

If experimental E_{c28} and E_{cmto} is available then:

Creep strain = stress [(1/ $E_{cmto(experimental)}$) + (creep coefficient/ $E_{cmto(average)}$)]

$$\text{Creep coefficient} = [\varphi(t)]\,[\varphi(t_c)]\sqrt{\frac{f_{cm28}}{f_{cmto}}}\left[1.5 + (2.86)\sqrt{\frac{4000}{f_{cmto}}}\,\frac{(1-1.086h^2)(t-t_o)}{t-t_o+32(V/S)^2}\right]$$

$$\varphi(t) = \frac{7.27 + \ln(t-t_o)}{17.18}$$

$$\varphi(t_c) = 1 \qquad \text{If } t_o = t_c$$

$$\varphi(t_c) = 1 - \sqrt{\frac{\varepsilon_{sh}(t_o - t_c)}{\varepsilon_{sh}(20000 - t_c)}} \qquad \text{If } t_o > t_c$$

I.4.7 Calculate Total Strain:

$\varepsilon(t)$ = Shrinkage strain + [(stress /E_{cmto}) (1 + creep coefficient)]

I.4.7.1 If experimental E_{c28} and E_{cmto} is available then:

$\varepsilon(t)$= Shrinkage strain + stress [(1/ $E_{cmto(experimental)}$) + (creep coefficient/ $E_{cmto(average)}$)]

I.4.8 Calculate Compliance Function:

$$\text{Compliance function} = \frac{(1 + \text{creep coefficient})}{E_{cmto}}$$

I.4.8.1 If experimental E_{c28} and E_{cmto} is available then:

Compliance function = [(1/ $E_{cmto(experimental)}$) + (creep coefficient/ $E_{cmto(average)}$)]

I.5 The SAK Model

I.5.1 Calculate Shrinkage Strain:

$$\varepsilon'_{cs}(t, t_o) = \varepsilon'_{sh}\,[1 - \exp\{-0.108(t - t_o)^{0.56}\}] \quad x \quad 10^{-5}$$

$$\varepsilon'_{sh} = -50 + 78\{1 - \exp(RH/100)\} + 38\,(\ln(w)) - 5[\ln\{(v/s)/10\}]^2 \ x \ 10^{-5}$$

I.5.2 Calculate Creep Strain:

$$\varepsilon'_{cc}(t, t', t_o) = (\varepsilon'_{bc} + \varepsilon'_{dc}) \ x\ [1 - \exp\{-0.09(t - t')^{0.6}\}] \quad x \quad 10^{-10}$$

$$\varepsilon'_{bc} = 15\,(c + w)^{2.0}\,(w/c)^{2.4}\,\{\ln(t')\}^{-0.67} \quad x \quad 10^{-10}$$

$$\varepsilon'_{dc} = 4500\,(w/c)^{4.2}(c + w)^{1.4}[\ln\{(v/s)/10\}]^{-2.2}\{1 - (RH/100)\}^{0.36}(t_o)^{-0.30} x\ 10^{-10}$$

I.5.3 Calculate Compliance Function:

Compliance Function $= \varepsilon'_{cc}(t, t', t_o) + (1/E_c(t_o))$

$E_c(t_o)$ is calculated utilizing the CEB 90 method

APPENDIX II: Examples of Shrinkage and Creep Calculations Utilizing all Five Models

Shrinkage Data Set (e_022_01): Type I (R), Cured for 28 days, Relative humidity = 50%, Mean 28-day concrete compressive strength = 6699 psi (46.2 MPa), volume-to-surface area ratio = 0.745 in. (19 mm), cement content = 24.72 lb/ft^3 (396 kg/m^3), water-to-cement ratio = 0.50, aggregate-to-cement ratio = 4.40, water content = 12.36 lb/ft^3 (198 kg/m^3). Experimental Modulus of elasticity is not available. Determine 92 day shrinkage after 28 days of curing.

Creep Data Set (c_006_07): Type I (R), Age of concrete at loading is 28 days, Relative humidity = 65%, Mean 28-day concrete compressive strength = 6800 psi (46.9 MPa), volume-to-surface area ratio = 0.984 in. (25 mm), cement content = 22.35 lb/ft^3 (358 kg/m^3), water-to-cement ratio = 0.52, aggregate-to-cement ratio = 5.0, water content = 11.62 lb/ft^3 (186 kg/m^3). Experimental Modulus of elasticity is not available. Determine 152 day creep compliance after loading at 28 days.

II.1 The ACI 209 Code Model

Shrinkage Strain:

$$\varepsilon_s(t) = \frac{t_s}{b + t_s} K_{SS} K_{SH} \varepsilon_{shu}$$

$b = 35$

$\varepsilon_{shu} = 780 \times 10^{-6}$ in./in.

$K_{SS} = 1.14 - 0.09(V/S) = 1.14 - 0.09\,(0.745) = 1.073$

$K_{SH} = 1.40 - 0.01H = 1.40 - 0.01\,(50) = 0.9$

$$\varepsilon_s(t) = \frac{92}{(35 + 92)} (1.073)(0.9)(780 \times 10^{-6}) = 546 \times 10^{-6}$$

Shrinkage Strain = 546×10^{-6}

Creep Compliance:

$$\text{Compliance function} = \frac{(1 + C_c(t))}{E_{cmto}}$$

$f'_{c(28)} = f_c'(t_o) = 6800.5$ psi

$E_{cmto} = 33(145)^{3/2}\,(6800.5)^{1/2} = 4.75 \times 10^6$ psi

$$C_c(t) = \frac{t^{0.60}}{10 + t^{0.60}} \quad C_{cu}\,K_{CH}\,K_{CA}\,K_{CS}$$

$C_{cu} = 2.35$

$K_{CH} = 1.27 - 0.0057(65) = 0.8345$

$K_{CA} = 1.25(180)^{-0.118} = 0.6773$

$K_{CS} = 1.14 - 0.09(0.984) = 1.051$

$$C_c(t) = \frac{(152)^{0.60}}{10 + (152)^{0.60}} \quad 2.35\,(0.8345)(0.6773)(1.051) = 0.936$$

$$\text{Creep Compliance} = \frac{(1 + 0.936)}{4.75 \times 10^6} = 0.410 \times 10^{-6}\ /\ \text{psi}$$

Creep Compliance = 0.410 microstrain /psi

II.2 The B3 Model

Shrinkage Strain:

$\varepsilon_{sh}\,(t, t_o) = \varepsilon_{sh\infty}\ K_h\ S(t)$

$\varepsilon_{sh\infty} = -\alpha_1\,\alpha_2(\,26\,(w)^{2.1}\,(f'_c)^{-0.28} + 270\,) \times 10^{-6}$

$\alpha_1 = 1.0$ for type I (R) cement

$\varepsilon_{sh\infty} = (1.0)\,(1.0)[26(12.36)^{2.1}\,(6699)^{-0.28} + 270] \times 10^{-6} = 703.44 \times 10^{-6}$

$K_h = 1 - h^3 = 1 - (0.5)^3 = 0.875$

$$S(t) = \tanh \sqrt{\frac{t - t_o}{T_{sh}}}$$

$T_{sh} = K_t \ (K_s D)^2$

$K_t = 190.8(28)^{-0.08} (6699)^{-0.25} = 16.15$

$K_s = 1.0, D = 2(0.745) = 1.49$

$T_{sh} = 16.15(1 \times 1.49)^2 = 35.85$

$$S(t) = \tanh \sqrt{\frac{120 - 28}{35.85}} = 0.922$$

$\varepsilon_{sh}(t, t_o) = 703.44 \times 10^{-6} (0.922)(0.875) = 567.46 \times 10^{-6}$

Shrinkage Strain = 567.46×10^{-6}

Creep Compliance:

$j(t, t') = q_1 + C_o(t, t') + C_d(t, t', t_o)$

$$q_1 = \frac{0.6 \times 10^6}{E_{28}}$$

$E_{28} = 57000 \ (f'_c)^{1/2} = 57000 \ (6800)^{1/2} = 4.7 \times 10^6$ psi

$$q_1 = \frac{0.6 \times 10^6}{4.7 \times 10^6} = 0.128$$

$C_o(t, t') = q_2 Q(t, t') + q_3 \ln(1 + (t - t')^n) + q_4 \ln(t / t')$

$q_2 = 451.1 \ (c)^{0.5} (f'_c)^{-0.9} = 451.1 \ (22.35)^{0.5} (6800)^{-0.9} = 0.758$

$q_3 = 0.29 \ (w/c)^4 \ q_2 = 0.29 \ (0.52)^4 \ 0.758 = 0.016$

$q_4 = 0.14 \ (a/c)^{-0.7} = 0.14 \ (5.0)^{-0.7} = 0.045$

$Q_f(t') = [\, 0.086 \ (t')^{2/9} + 1.21 \ (t')^{4/9}]^{-1}$

$$= [\,0.086\,(28)^{2/9} + 1.21\,(28)^{4/9}]^{-1} = 0.182$$

$$Z(t,t') = (t')^{-m}\ \ln(1+(t-t')^{n}) = (28)^{-0.5}\ \ln(1+(180-28)^{0.1}) = 0.184$$

$$r(t') = 1.7\,(t')^{0.12} + 8 = 1.7\,(28)^{0.12} + 8 = 10.536$$

$$Q(t,t') = Q_f(t')\left[1 + \frac{(Q_f(t'))^{r(t')}}{Z(t,t')^{r(t')}}\right]^{-1/r(t')}$$

$$Q(t,t') = 0.182\left[1 + \frac{0.182^{10.536}}{0.184^{10.536}}\right]^{-1/10.536}$$

$$= 0.1713$$

$$C_o(t,t') = q_2\,Q(t,t') + q_3 \ln(1 + (t-t')^{n}) + q_4 \ln\ (t/t')$$

$$= 0.758(0.1713) + 0.016 \ln[1+(180\text{-}28)^{0.1}) + 0.045 \ln(180/28)$$

$$= 0.23$$

$$C_d(t,t',t_o) = q_5\,[\exp\{-8H(t)\} - \exp\{-8H(t')\}]^{1/2}$$

$$q_5 = 7.57 \times 10^{5}(f'_c)^{-1}\ \mathrm{ABS}(\varepsilon_{sh\infty})^{-0.6}$$

$$\varepsilon_{sh\infty} = -\alpha_1\,\alpha_2(\,26\,(w)^{2.1}\,(f'_c)^{-0.28} + 270\,)$$

$\alpha_1 = 1.0$ for type I (R) cement

$$\varepsilon_{sh\infty} = (1.0)\,(1.0)[26(11.62)^{2.1}\,(6800)^{-0.28} + 270] = 649$$

$$q_5 = 7.57 \times 10^{5}(6800)^{-1}\ \mathrm{ABS}(649)^{-0.6} = 2.3$$

$$H(t) = 1 - (1-h)\,S(t)$$

$$S(t) = \tanh\sqrt{\frac{t-t_o}{T_{sh}}}$$

$$T_{sh} = K_t\,(K_s\,D)^2$$

$$K_t = 190.8(28)^{-0.08}\,(6800)^{-0.25} = 16.09$$

$$K_s = 1.0,\ D = 2(0.984) = 1.968$$

$$T_{sh} = 16.09(1 \times 1.968)^2 = 62.32$$

$$S(t) = \tanh\sqrt{\frac{180-28}{62.32}} = 0.916$$

$$H(t) = 1-(1-0.65)\,(0.916) = 0.6794$$

$$H(t') = 1-(1-h)\,S(t')$$

$$S(t') = \tanh\sqrt{\frac{t'-t_o}{T_{sh}}}$$

$$S(t') = \tanh\sqrt{\frac{28-28}{62.32}} = 0$$

$$H(t') = 1-(1-0.65)\,(0) = 1$$

$$C_d(t, t', t_o) = 2.3[\exp\{-8(0.6794)\} - \exp\{-8(1)\}]^{1/2} = 0.146$$

$$j(t, t') = 0.128 + 0.23 + 0.146 = 0.504 \times 10^{-6}\ /\ \text{psi}$$

Creep Compliance = 0.504 microstrain /psi

II.3 The CEB 90 Code Model

Shrinkage Strain:

$$\varepsilon_{cs}(t-t_s) = (\varepsilon_{cso})\,\beta_s(t-t_s)$$

$$\varepsilon_{cso} = \varepsilon_s(f_{cm})\,(\beta_{RH})$$

$$\varepsilon_s(f_{cm}) = [160 + 10\,\beta_{sc}\,(9 - f_{cm}/1450)\,] \times 10^{-6}$$

$\beta_{sc} = 5$ for type I (R) cement

$$\varepsilon_s(f_{cm}) = [160 + 10\,(5)\,(9 - 6699/1450)\,] \times 10^{-6} = 379 \times 10^{-6}$$

$$\beta_{RH} = -1.55\ \beta_{ARH}$$

$$\beta_{ARH} = 1 - (RH/100)^3 = 1 - (50/100)^3 = 0.875$$

$$\beta_{RH} = -1.55\ (0.875) = -1.356$$

$$\varepsilon_{cso} = (379 \times 10^{-6})(-1.356) = -513.9 \times 10^{-6}$$

$$\beta_s(t-t_s) = \sqrt{\frac{(t-t_s)}{\{350(h_o/4)^2\} + (t-t_s)}}$$

$$\beta_s(t-t_s) = \sqrt{\frac{(120-28)}{\{350(0.745x2/4)^2\} + (120-28)}} = 0.81$$

$$\varepsilon_{cs}(t-t_s) = (-513.9 \times 10^{-6})(0.81) = -416.3 \times 10^{-6}$$

(Shrinkage is given as negative and swelling as positive in this model.)

Shrinkage Strain = -416.3×10^{-6}

Creep Compliance:

$$E_c = (E_{co})(f_{cm} / 1450)^{1/3} = (3117500)(6800 / 1450)^{1/3} = 4.956 \times 10^6$$

$$E_c(t_o) = (E_c)\{\exp[0.5S(1 - (28/t_o)^{0.5})]\}$$

S = 0.25 for type I (R) cement

$$= (4.956 \times 10^6)\{\exp[0.5(0.25)(1 - (28/28)^{0.5})]\}$$

$$= 4.956 \times 10^6$$

$$\phi(t, t_o) = (\phi_o)\ \beta_c(t-t_o)$$

$$\phi_o = \phi_{RH}\,\beta\,(f_{cm}) \times \beta(t_o)$$

$$\phi_{RH} = 1 + \frac{(1 - RH/100)}{0.46(h_o/4)^{1/3}}$$

$$= 1 + \frac{(1 - 65/100)}{0.46(0.984x2/4)^{1/3}} = 1.94$$

$$\beta(f_{cm}) = 5.3 / (f_{cm}/1450)^{1/2} = 5.3 / (6800/1450)^{1/2} = 2.447$$

$$\beta(t_o) = (0.1 + t_o^{0.20})^{-1} = (0.1 + 28^{0.20})^{-1} = 0.488$$

$$\phi_o = (1.94)(2.447)(0.488) = 2.317$$

$$\beta_c(t\text{-}t_o) = \frac{(t - t_o)^{0.3}}{\{\beta_H + (t - t_o)\}^{0.3}}$$

$$\beta_H = 150 [1 + (0.012RH)^{18}] (h_o/4) + 250$$

$$= 150 [1 + (0.012(65)^{18}] (0.984x2/4) + 250 = 324.6$$

$$\beta_c(t\text{-}t_o) = \frac{(180 - 28)^{0.3}}{\{324.6 + (180 - 28)\}^{0.3}} = 0.710$$

$$\phi(t, t_o) = (2.317)(0.710) = 1.645$$

$$\text{Compliance function} = \frac{\phi(t, t_o)}{E_c} + \frac{1}{E_c(t_o)}$$

$$= \frac{1.645 + 1}{4.956 \times 10^6} = 0.534 \times 10^{-6}/\text{ psi}$$

Creep Compliance = 0.534 microstrain/psi

II.4 The GZ Model

Shrinkage Strain:

$$\varepsilon_{sh} = (\varepsilon_{shu})\ \beta(h)\ \beta(t)$$

$$\beta(h) = 1 - 1.18(h)^4 = 1 - 1.18(0.50)^4 = 0.926$$

$$\beta(t) = \frac{7.27 + \ln(t - t_c)}{17.18} \quad x \quad \frac{t - t_c}{t - t_c + 9.7(V/S)^2}$$

$$= \frac{7.27 + \ln(120 - 28)}{17.18} \quad x \quad \frac{120-28}{120-28 + 9.7(0.745)^2}$$

$$= 0.6483$$

$$\varepsilon_{shu} = 857 \; K\left[\frac{f_{cm28}}{f_{cmtc}}\right]^{1/2}\left[\frac{4000}{f_{cm28}}\right]^{1/2} \; x \; 10^{-6}$$

K = 1.0 for type I (R) cement

$$= 857 x 1.0\left[\frac{6699}{6699}\right]^{1/2}\left[\frac{4000}{6699}\right]^{1/2} \; x \; 10^{-6}$$

$$= 662.2 \text{ x } 10^{-6}$$

$$\varepsilon_{sh} = (662.2 \text{ x } 10^{-6})(0.926)(0.6483) = 397.5 \text{ x } 10^{-6}$$

Shrinkage Strain = 397.5×10^{-6}

<u>Creep Compliance</u>:

$f_{cmto} = f_{cm28} = 6800.5$

$E_{cmto} = 500000 + 52000\,(6800.5)^{1/2} = 4.79 \text{ x } 10^6$

Creep coefficient = $[\varphi(t)]\,[\varphi(t_c)]\sqrt{\frac{f_{cm28}}{f_{cmto}}}\left[1.5 + (2.86)\sqrt{\frac{4000}{f_{cmto}}}\;\frac{(1-1.086h^2)(t - t_o)}{t - t_o + 32(V/S)^2}\right]$

$$\varphi(t) = \frac{7.27 + \ln(t - t_o)}{17.18}$$

$$= \frac{7.27 + \ln(180 - 28)}{17.18} = 0.1756$$

$\varphi(t_c) = 1$

$$\text{Creep coefficient} = [0.1756]\,[1]\sqrt{\frac{6800}{6800}}\left[1.5+(2.86)\sqrt{\frac{4000}{6800}}\;\left(1-\frac{1.086(0.65)^2)(180-28)}{180-28+32(0.984)^2}\right)\right]$$

$$= 1.78$$

$$\text{Compliance function} = \frac{(1 + \text{creep coefficient})}{E_{cmto}} = \frac{1 + 1.78}{4.79 \times 10^6}$$

$$= 0.58 \times 10^{-6}\ /\text{psi}$$

Creep Compliance = 0.58 microstrain /psi

II.5 The SAK Model

Shrinkage Strain:

$$\varepsilon'_{cs}(t, t_o) = \varepsilon'_{sh}\,[1-\exp\{-0.108(t-t_o)^{0.56}\}]$$

$$\varepsilon'_{sh} = -50 + 78\{1-\exp(RH/100)\} + 38\,(\ln(w)) - 5[\ln\{(v/s)/10\}]^2 \times 10^{-5}$$

$$\varepsilon'_{sh} = -50 + 78\{1-\exp(50/100)\} + 38\,(\ln(198)) - 5[\ln\{(19)/10\}]^2 \times 10^{-5}$$

$$= 97.34 \times 10^{-5}$$

$$\varepsilon'_{cs}(t, t_o) = 97.34\,[1-\exp\{-0.108(120-28)^{0.56}\}] \times 10^{-5}$$

$$= 72.32 \times 10^{-5}$$

Shrinkage Strain = 723.2 x 10^{-6}

Creep Compliance:

$$\varepsilon'_{cc}(t, t', t_o) = (\varepsilon'_{bc} + \varepsilon'_{dc}) \times [1-\exp\{-0.09(t-t')^{0.6}\}]$$

$$\varepsilon'_{bc} = 15\,(c+w)^{2.0}\,(w/c)^{2.4}\,\{\ln(t')\}^{-0.67} \times 10^{-10}$$

$$\varepsilon'_{bc} = 15\,(358+186)^{2.0}\,(0.52)^{2.4}\,\{\ln(28)\}^{-0.67} \times 10^{-10}$$

$= 412043 \times 10^{-10}$

$\varepsilon'_{dc} = 4500\,(w/c)^{4.2}(c + w)^{1.4}[\ln\{(v/s)/10\}]^{-2.2}\{1 - (RH/100)\}^{0.36}(t_o)^{-0.30} \times 10^{-10}$

$\varepsilon'_{dc} = 4500\,(0.52)^{4.2}(358 + 186)^{1.4}[\ln\{(25)/10\}]^{-2.2}\{1 - (65/100)\}^{0.36}(28)^{-0.30} \times 10^{-10}$

$= 600263.6 \times 10^{-10}$

$\varepsilon'_{bc} + \varepsilon'_{dc} = 1012306.6 \times 10^{-10}$

$\varepsilon'_{cc}(t, t', t_o) = (1012306.6 \times 10^{-10}) \times [1 - \exp\{-0.09(180 - 28)^{0.6}\}]$

$= 850532.53 \times 10^{-10}/\text{N/mm}^2$

$= 0.5864 \times 10^{-6}/\text{psi}$

Compliance Function $= \varepsilon'_{cc}(t, t', t_o) + (1/E_c(t_o))$

$= 0.5864 \times 10^{-6} + (1/4.79 \times 10^{6})$

$= 0.80 \times 10^{-6}$ /psi

$E_c(t_o)$ is calculated utilizing the CEB 90 method

Creep Compliance = 0.80 microstrain /psi

Appendix III: Example of Calculating the Coefficient of Variation for a Model as Suggested by the B3 Method

Example: An experimental data set j was taken from the data bank and the coefficient of variation was calculated for creep compliance for a given model.

(In this example the ACI 209 model was used.)

Data Point Number (i)	Decade in which the data point falls	Creep duration (days)	Experimental creep compliance microstrain/psi	Predicted creep compliance of the ACI 209 model microstrain/psi (J_{ij})
1	2	40	0.3930	0.484969
2	3	161	0.5722	0.575080
3	3	241	0.6343	0.597708
4	3	300	0.6619	0.609015
5	3	700	0.7653	0.645827
n = 6	$n_d = 2$	900	0.7722	0.654652

Number of data set selected = 1 = Data set number = j

Total number of points in this data set = n = 6

Number of points in decade 1 (0 days-10 days) $= n_1 = 0$

Number of points in decade 2 (10 days-100 days) $= n_2 = 1$

Number of points in decade 3 (100 days-1000 days) $= n_3 = 5$

Total number of decades in this data set $= n_d = 2$ (decade 2 and decade 3)

Weight assigned to the data point in decade 2 is calculated as follows

$$\omega_{ij} = \frac{n}{n_d\, n_2} = \frac{6}{2 \times 1} = 3.0 \quad (\text{for } i = 1, j = 1)$$

Weight assigned to the data points in decade 3 is calculated as follows

$$\omega_{ij} = \frac{n}{n_d\, n_3} = \frac{6}{2 \times 5} = 0.6 \quad (\text{for } i = 2 \text{ to } 6,\ j = 1)$$

Weights assigned to each data points (ω_{ij})	Predicted compliance (J_{ij})	Difference between the predicted compliance and the experimental creep compliance (Δ_{ij})	($\omega_{ij}\, J_{ij}$)	$(\omega_{ij}\, \Delta_{ij})^2$
$\omega_{11} = 3.0$	0.484969	0.092	1.455	0.0762
$\omega_{21} = 0.6$	0.575080	0.0029	0.345	$3\text{x}10^{-6}$
$\omega_{31} = 0.6$	0.597708	−0.0366	0.359	0.00048
$\omega_{41} = 0.6$	0.609015	−0.053	0.365	0.001
$\omega_{51} = 0.6$	0.645827	−0.1195	0.387	0.0051
$\omega_{61} = 0.6$	0.654652	−0.1175	0.393	0.005
$\Sigma\, \omega_{ij} = n_w = 6$			$\Sigma\, (\omega_{ij}\, J_{ij}) = 3.304$	$\Sigma\, (\omega_{ij}\, \Delta_{ij})^2 = 0.0878$

For data set $j = 1$, $\bar{J}_1$ is calculated as follows

$$\bar{J}_j = \frac{1}{n_w} \times \Sigma(\omega_{ij}\, J_{ij})$$

$$\bar{J}_1 = \frac{1}{6} \times (3.304) = 0.55$$

$$\varpi_j = \frac{1}{\bar{J}_j} \sqrt{\frac{1}{n-1} \times \Sigma(\omega_{ij}\, \Delta_{ij})^2} \times 100$$

$$\varpi_1 = \frac{1}{0.55} \sqrt{\frac{1}{6-1} \times (0.0878)} \times 100 = 24\%$$

Coefficient of variation (ω_1) in percentage for data set j = 1 is 24%

APPENDIX IV: Shrinkage Experimental Data Sets from the RILEM Data Bank Utilized in this Study

Set No.	Author Name	File No.	w/c	a/c	c	Type European	Type American	$f'_{c(28)}$	$E_{c(28)}$	D	t_s	H	α_1	β_{sc}	K
1	Hummel	e_011_05	0.55	5.4	334	R	I	41.9	29950	100	7	65	1	5	1
2	Wallo	e_022_01	0.5	4.4	396	R	I	46.2	N/A	38	28	50	1	5	1
3	Wallo	e_022_02	0.5	4.4	396	R	I	46.2	N/A	51	28	50	1	5	1
4	Wallo	e_022_03	0.5	4.4	396	R	I	46.2	N/A	76	28	50	1	5	1
5	Wallo	e_022_04	0.5	4.4	396	R	I	46.2	N/A	38	28	50	1	5	1
6	Wallo	e_022_05	0.5	4.4	396	R	I	46.2	N/A	51	28	50	1	5	1
7	Wallo	e_022_06	0.5	4.4	396	R	I	46.2	N/A	76	28	50	1	5	1
8	Rüsch	e_030_02	0.55	5.4	336	R	I	28.3	28700	60	7	65	1	5	1
9	Rüsch	e_030_03	0.49	5.3	344	R	I	47.8	35600	60	7	65	1	5	1
10	Wischer	e_061_02	0.48	5.9	325	R	I	50.3	35020	75	8	65	1	5	1
11	Wischer	e_061_03	0.48	5.9	325	R	I	50.3	35020	75	28	65	1	5	1
12	Wischer	e_061_05	0.48	4.2	410	R	I	46.4	32790	75	10	65	1	5	1
13	Wischer	e_061_06	0.48	4.2	410	R	I	46.4	32790	75	28	65	1	5	1
14	Wesche	e_063_02	0.55	5.4	336	R	I	33.2	32200	100	7	65	1	5	1
15	Brooks	e_072_06	0.36	3.3	520	R	I	70.9	37800	38	28	65	1	5	1
16	Brooks	e_072_08	0.34	2.6	608	R	I	69.1	37800	38	28	65	1	5	1
17	Brooks	e_072_09	0.27	2.6	628	R	I	80.9	37800	38	28	65	1	5	1
18	Brooks	e_072_10	0.3	2.1	725	R	I	67.3	37800	38	28	65	1	5	1
19	Russel	e_078_01	0.43	4	432	R	I	52.4	31556	76	7	50	1	5	1
20	Russel	e_078_02	0.39	3.3	502	R	I	63	36241	76	7	50	1	5	1
21	Shritharan	e_079_01	0.47	5.1	390	R	I	50.1	29800	50	8	60	1	5	1
22	Shritharan	e_079_02	0.47	5.1	391	R	I	50.1	29800	75	8	60	1	5	1
23	Shritharan	e_079_03	0.47	5.1	392	R	I	50.1	29800	100	8	60	1	5	1
24	Shritharan	e_079_04	0.47	5.1	393	R	I	50.1	29800	150	8	60	1	5	1
25	Shritharan	e_079_05	0.47	5.1	393	R	I	50.1	29800	200	8	60	1	5	1
26	Pentala	e_081_07	0.52	5.2	350	R	I	59.1	N/A	52	7	60	1	5	1
27	Pentala	e_081_08	0.52	5.2	350	R	I	59.1	N/A	52	7	45	1	5	1
28	Wittmann	e_083_01	0.48	5.4	350	R	I	33.2	36300	42	7	65	1	5	1
29	Wittmann	e_083_02	0.48	5.4	350	R	I	33.2	36300	80	7	65	1	5	1
30	Wittmann	e_083_03	0.48	5.4	350	R	I	33.2	36300	150	7	65	1	5	1
31	Hammer	e_088_02	0.3	4.2	450	R	I	70.9	52100	50	30	65	1	5	1
32	Hammer	e_088_06	0.3	3.6	500	R	I	75.6	43700	50	28	65	1	5	1
33	Hummel	e_011_01	0.55	5.4	334	SL	II	26.9	23900	100	7	65	0.85	4	0.7
34	Hummel	e_011_02	0.38	5.4	350	SL	II	43.1	30610	100	7	65	0.85	4	0.7
35	Hummel	e_011_03	0.45	5.4	345	SL	II	35.3	31880	100	7	65	0.85	4	0.7

Set No.	Author Name	File No.	w/c	a/c	c	Type European	Type American	$f'_{c(28)}$	$E_{c(28)}$	D	t_s	H	α_1	β_{sc}	K
36	Rüsch	e_014_01	0.55	5.4	337	SL	II	24.4	20620	100	7	65	0.85	4	0.7
37	Rüsch	e_014_02	0.55	5.5	337	SL	II	25.8	32790	100	7	65	0.85	4	0.7
38	Rüsch	e_014_03	0.55	5.4	337	SL	II	26.4	26670	100	7	65	0.85	4	0.7
39	Rüsch	e_014_05	0.55	5.5	337	SL	II	27.8	22370	100	7	65	0.85	4	0.7
40	Wesche	e_063_07	0.55	5.4	336	SL	II	33.9	27800	100	7	65	0.85	4	0.7
41	Wesche	e_063_08	0.55	5.4	336	SL	II	33.1	35400	100	7	65	0.85	4	0.7
42	Wesche	e_063_09	0.55	5.4	336	SL	II	30.5	28400	100	7	65	0.85	4	0.7
43	Aschl	e_067_01	0.52	5.1	351	SL	II	55.1	N/A	75	28	65	0.85	4	0.7
44	Stöckl	e_069_03	0.45	5.4	353	SL	II	23.9	24090	75	7	65	0.85	4	0.7
45	Hammer	e_088_20	0.3	4.2	450	SL	II	55.9	43100	50	29	65	0.85	4	0.7
46	York	e_037_01	0.43	4.6	404	SL	II	44.2	N/A	76	90	60	0.85	4	0.7
47	McDonald	e_051_03	0.33	3.8	466	SL	II	46.1	N/A	76	90	50	0.85	4	0.7
48	McDonald	e_051_07	0.43	4.6	404	SL	II	51.2	N/A	76	90	50	0.85	4	0.7
49	McDonald	e_051_11	0.43	3.7	460	SL	II	46.1	N/A	76	90	50	0.85	4	0.7
50	Keeton	e_015_02	0.46	3.7	452	RS	III	45.2	25860	38	8	50	1.1	8	1.33
51	Keeton	e_015_03	0.46	3.7	452	RS	III	45.2	25860	38	8	75	1.1	8	1.33
52	Keeton	e_015_07	0.46	3.7	452	RS	III	45.2	25860	51	8	50	1.1	8	1.33
53	Keeton	e_015_08	0.46	3.7	452	RS	III	45.2	25860	51	8	75	1.1	8	1.33
54	Keeton	e_015_10	0.46	3.7	452	RS	III	45.2	25860	76	8	50	1.1	8	1.33
55	Keeton	e_015_11	0.46	3.7	452	RS	III	45.2	25860	76	8	75	1.1	8	1.33
56	Keeton	e_015_16	0.46	3.7	452	RS	III	45.2	25860	38	8	50	1.1	8	1.33
57	Keeton	e_015_17	0.46	3.7	452	RS	III	45.2	25860	38	8	75	1.1	8	1.33
58	Keeton	e_015_18	0.46	3.7	452	RS	III	45.2	25860	76	8	75	1.1	8	1.33
59	Keeton	e_015_22	0.46	3.7	452	RS	III	45.2	25860	38	24	50	1.1	8	1.33
60	Keeton	e_015_23	0.46	3.7	452	RS	III	45.2	25860	26	8	50	1.1	8	1.33
61	Keeton	e_015_24	0.46	3.7	452	RS	III	45.2	25860	38	8	50	1.1	8	1.33
62	Keeton	e_015_25	0.46	3.7	452	RS	III	45.2	25860	76	8	50	1.1	8	1.33
63	Keeton	e_015_26	0.46	3.7	452	RS	III	45.2	25860	153	8	50	1.1	8	1.33
64	Keeton	e_015_27	0.46	3.7	452	RS	III	45.2	25860	178	8	50	1.1	8	1.33
65	Hanson	e_020_01	0.71	6	303	RS	III	41.3	27700	51	8	50	1.1	8	1.33
66	Hanson	e_020_02	0.71	6	303	RS	III	41.3	27700	76	8	50	1.1	8	1.33
67	Hanson	e_020_03	0.71	6	303	RS	III	41.3	27700	102	8	50	1.1	8	1.33
68	Hanson	e_020_04	0.71	6	303	RS	III	41.3	27700	153	8	50	1.1	8	1.33
69	Hanson	e_020_05	0.71	6	303	RS	III	41.3	27700	203	8	50	1.1	8	1.33
70	Hanson	e_020_06	0.71	6	303	RS	III	41.3	27700	254	8	50	1.1	8	1.33
71	Hanson	e_020_07	0.71	6	303	RS	III	41.3	27700	304	8	50	1.1	8	1.33
72	Hanson	e_020_08	0.71	6	303	RS	III	41.3	27700	203	8	50	1.1	8	1.33
73	Hanson	e_020_09	0.71	6	303	RS	III	41.3	27700	102	8	50	1.1	8	1.33
74	Hanson	e_020_10	0.71	6	303	RS	III	41.3	27700	51	8	50	1.1	8	1.33

Set No.	Author Name	File No.	w/c	a/c	c	Type European	Type American	$f'_{c(28)}$	$E_{c(28)}$	D	t_s	H	α_1	β_{sc}	K
75	Rüsch	e_030_07	0.49	4.4	401	RS	III	43.8	37000	60	7	65	1.1	8	1.33
76	Wischer	e_061_09	0.48	5.9	325	RS	III	56.3	37450	75	28	65	1.1	8	1.33
77	Wischer	e_061_12	0.48	4.2	410	RS	III	50.8	30700	75	28	65	1.1	8	1.33
78	Wischer	e_061_15	0.4	4.5	400	RS	III	60.3	38910	75	28	65	1.1	8	1.33
79	Wesche	e_063_05	0.55	5.4	337	RS	III	46.5	37500	100	7	65	1.1	8	1.33
80	Hilsdorf	e_091_03	0.55	5.4	337	RS	III	40.3	30200	100	7	65	1.1	8	1.33
81	Hilsdorf	e_091_04	0.55	5.4	337	RS	III	40.3	30200	100	28	65	1.1	8	1.33
82	Hilsdorf	e_091_05	0.55	5.4	337	RS	III	40.3	30200	100	90	65	1.1	8	1.33

w/c = Water-to-cement ratio

a/c = Aggregate-to-cement ratio

c = Cement content in kg/m^3

Type = Type of cement

$f'_{c(28)}$ = 28-day mean cylindrical concrete compressive strength in MPa

$E_{c(28)}$ = 28-day modulus of elasticity in MPa

D = 2Ac/U = Area of member to its perimeter ratio

t_s = Age of concrete at the beginning of shrinkage

H = Relative humidity in percentage

α_1 = Correction factor for type of cement in the B3 model

β_{sc} = Correction factor for type of cement in the CEB 90 model

K = Correction factor for type of cement in the GZ model

Note: Data sets in Appendix IV is grouped according to type of cement

APPENDIX V: Creep Experimental Data Sets from the RILEM Data Bank Utilized in this Study

Set No.	Author Name	File No.	w/c	a/c	c	Type European	Type American	$f'_{c(28)}$	$E_{c(28)}$	D	t_o	H
1	Dutron	c_001_01	0.56	6.46	289	R	I	28.4	N/A	100	60	47.5
2	Dutron	c_001_02	0.56	6.46	289	R	I	28.4	N/A	100	60	47.5
3	Dutron	c_001_05	0.56	6.46	289	R	I	28.4	N/A	100	60	67.5
4	Dutron	c_001_06	0.56	6.46	289	R	I	28.4	N/A	100	60	47.5
5	Weil	c_006_07	0.52	5.03	358	R	I	46.9	N/A	50	28	65
6	Weil	c_006_08	0.52	5.03	358	R	I	46.9	N/A	50	28	65
7	Weil	c_006_11	0.52	5.03	358	R	I	46.9	N/A	50	28	65
8	Weil	c_006_12	0.52	5.03	358	R	I	46.9	N/A	50	28	65
9	Hummel	c_011_05	0.55	5.40	334	R	I	41.9	N/A	100	28	65
10	Hummel	c_011_06	0.55	5.40	334	R	I	41.9	N/A	100	90	65
11	L'Hermite	c_017_01	0.49	4.81	350	R	I	33.9	N/A	35	7	50
12	Mammillan	c_017_02	0.49	4.81	350	R	I	33.9	N/A	35	21	50
13	Mammillan	c_017_03	0.49	4.81	350	R	I	33.9	N/A	35	90	50
14	Mammillan	c_017_05	0.49	4.81	350	R	I	33.9	N/A	35	7	50
15	Mammillan	c_017_06	0.49	4.81	350	R	I	33.9	N/A	35	21	50
16	Mammillan	c_017_07	0.49	4.81	350	R	I	33.9	N/A	35	28	50
17	Mammillan	c_017_08	0.49	4.81	350	R	I	33.9	N/A	35	90	50
18	Mammillan	c_017_27	0.49	4.81	350	R	I	33.9	N/A	35	28	50
19	Mammillan	c_017_28	0.49	4.81	350	R	I	33.9	N/A	35	28	75
20	Rostasy	c_043_01	0.56	7.10	275	R	I	41.4	N/A	100	28	65
21	Rostasy	c_043_02	0.41	5.59	332	R	I	40.9	N/A	100	28	65
22	Lambotte	c_058_01	0.5	6.30	300	R	I	29.2	N/A	75	28	60
23	Lambotte	c_058_02	0.44	5.27	360	R	I	41.9	N/A	75	15	60
24	Lambotte	c_058_03	0.44	5.27	360	R	I	37.8	N/A	75	7	60
25	Lambotte	c_058_04	0.47	5.23	375	R	I	39	N/A	75	17	60
26	Lambotte	c_058_06	0.52	5.57	350	R	I	30.8	N/A	50	60	60
27	Lambotte	c_058_07	0.5	6.30	300	R	I	29.2	N/A	75	28	60
28	Lambotte	c_058_08	0.5	5.31	350	R	I	33.6	N/A	75	28	60
29	Lambotte	c_058_09	0.47	5.23	375	R	I	39.4	N/A	75	7	60
30	Lambotte	c_058_10	0.35	4.66	400	R	I	45.3	N/A	75	28	60
31	Lambotte	c_058_11	0.575	4.84	400	R	I	46.2	N/A	75	7	60
32	Lambotte	c_058_12	0.4	4.53	450	R	I	38.9	N/A	75	28	60
33	Lambotte	c_058_16	0.52	5.57	350	R	I	34.1	N/A	50	17	60
34	Lambotte	c_058_18	0.57	5.97	325	R	I	36.6	N/A	50	28	60
35	Wischers	c_061_02	0.48	5.86	325	R	I	50.5	N/A	75	8	65

Set No.	Author Name	File No.	w/c	a/c	c	Type European	Type American	$f'_{c(28)}$	$E_{c(28)}$	D	t_o	H
36	Wischers	c_061_03	0.48	5.86	325	R	I	50.5	N/A	75	28	65
37	Wischers	c_061_05	0.48	4.24	410	R	I	46.4	N/A	75	10	65
38	Wischers	c_061_06	0.48	4.24	410	R	I	46.4	N/A	75	28	65
39	Wesche	c_063_02	0.55	5.39	336	R	I	33.2	32200	100	7	65
40	Wesche	c_063_03	0.55	5.39	336	R	I	33.2	32200	100	28	65
41	Wesche	c_063_06	0.55	5.41	335	R	I	33.2	N/A	100	28	65
42	Wesche	c_063_15	0.515	5.41	332	R	I	34.9	N/A	100	28	65
43	Wesche	c_063_16	0.545	5.86	312	R	I	34.9	N/A	100	28	65
44	Wesche	c_063_17	0.485	5.41	332	R	I	39.9	N/A	100	28	65
45	Wesche	c_063_18	0.5	5.40	335	R	I	39.1	N/A	100	28	65
46	Brooks	c_072_06	0.36	3.30	520	R	I	70.9	N/A	38	28	65
47	Brooks	c_072_08	0.34	2.60	608	R	I	69.1	N/A	38	28	65
48	Brooks	c_072_09	0.27	2.60	628	R	I	80.9	N/A	38	28	65
49	Brooks	c_072_10	0.3	2.08	725	R	I	67.3	N/A	38	28	65
50	Stöckl	c_073_01	0.55	5.35	336	R	I	30.3	N/A	60	57	65
51	Stöckl	c_073_02	0.55	5.35	336	R	I	30.3	N/A	60	57	65
52	Russel	c_078_02	0.432	4.04	432	R	I	52.4	31556	76	28	50
53	Russel	c_078_06	0.39	3.34	502	R	I	63	36241	76	28	50
54	Summer	c_088_02	0.3	4.22	450	R	I	70.9	N/A	50	30	65
55	Summer	c_088_05	0.3	3.63	500	R	I	75.6	N/A	50	30	65
56	Summer	c_088_13	0.38	3.99	450	R	I	57.7	N/A	50	32	65
57	Summer	c_088_35	0.3	4.22	450	R	I	70.9	N/A	50	28	65
58	Summer	c_088_39	0.48	3.72	450	R	I	48.74582	N/A	50	28	65
59	Shritharan	c_079_01	0.47	5.09	390	R	I	50.1	29800	75	8	60
60	Shritharan	c_079_02	0.47	5.09	391	R	I	50.1	29800	75	14	60
61	Shritharan	c_079_03	0.47	5.09	392	R	I	50.1	29800	75	21	60
62	Shritharan	c_079_04	0.47	5.09	393	R	I	50.1	29800	75	28	60
63	Shritharan	c_079_05	0.47	5.09	394	R	I	50.1	29800	75	84	60
64	Shritharan	c_079_13	0.47	5.09	402	R	I	50.1	29800	50	8	60
65	Shritharan	c_079_14	0.47	5.09	403	R	I	50.1	29800	100	8	60
66	Shritharan	c_079_15	0.47	5.09	404	R	I	50.1	29800	150	8	60
67	Shritharan	c_079_16	0.47	5.09	405	R	I	50.1	29800	200	8	60
68	Seki	c_044_01	0.399	5.60	343	R	I	27.9	22700	75	28	50
69	Seki	c_044_03	0.399	5.60	343	R	I	27.9	22700	75	96	50
70	Kawasumi	c_046_02	0.4	5.60	343	R	I	44.5	N/A	75	28	50
71	Kawasumi	c_046_04	0.4	5.60	343	R	I	44.5	N/A	75	96	50
72	Okajima	c_055_01	0.53	5.49	334	R	I	42	30000	25	30	50
73	Weil	c_006_01	0.52	5.39	338	SL	II	25.4	N/A	50	28	65
74	Weil	c_006_02	0.52	5.39	338	SL	II	25.4	N/A	100	28	65

Set No.	Author Name	File No.	w/c	a/c	c	Type European	Type American	$f'_{c(28)}$	$E_{c(28)}$	D	t_o	H
75	Weil	c_006_03	0.52	5.39	338	SL	II	25.4	N/A	150	28	65
76	Weil	c_006_04	0.52	5.39	338	SL	II	25.4	N/A	300	28	65
77	Weil	c_006_05	0.54	5.40	337	SL	II	28	N/A	50	28	65
78	Weil	c_006_06	0.54	5.40	337	SL	II	28	N/A	50	28	65
79	Weil	c_006_09	0.54	5.40	337	SL	II	28	N/A	50	28	65
80	Weil	c_006_10	0.54	5.40	337	SL	II	28	N/A	50	28	65
81	Hummel	c_011_02	0.55	5.40	334	SL	II	26.9	N/A	100	28	65
82	Hummel	c_011_03	0.55	5.40	334	SL	II	26.9	N/A	100	90	65
83	Hummel	c_011_07	0.38	5.39	350	SL	II	43.1	N/A	100	28	65
84	Hummel	c_011_08	0.45	5.39	345	SL	II	35.3	N/A	100	28	65
85	Rüsch	c_014_01	0.55	5.39	337	SL	II	24.4	20620	100	28	65
86	Rüsch	c_014_02	0.55	5.47	337	SL	II	25.8	32790	100	28	65
87	Rüsch	c_014_03	0.55	5.40	337	SL	II	26.4	26670	100	27	65
88	Rüsch	c_014_05	0.55	5.50	337	SL	II	27.8	22370	100	28	65
89	Rüsch	c_014_06	0.55	6.26	337	SL	II	28.4	30310	100	28	65
90	Wesche	c_063_24	0.55	5.39	336	SL	II	34.1	27800	100	7	65
91	Wesche	c_063_25	0.55	5.39	336	SL	II	34.1	27800	100	28	65
92	Wesche	c_063_27	0.55	5.39	336	SL	II	33.2	35400	100	7	65
93	Wesche	c_063_28	0.55	5.39	336	SL	II	33.2	35400	100	28	65
94	Wesche	c_063_30	0.55	5.39	336	SL	II	30.8	28400	100	7	65
95	Wesche	c_063_31	0.55	5.39	336	SL	II	30.8	28400	100	28	65
96	Stöckl	c_069_05	0.45	5.41	353	SL	II	23.9	N/A	75	28	65
97	Stöckl	c_069_06	0.45	5.41	353	SL	II	23.9	N/A	75	28	65
98	Summer	c_088_15	0.3	4.19	450	SL	II	55.9	N/A	50	30	65
99	York	c_037_02	0.426	4.62	404	SL	II	45	N/A	76.2	90	60
100	York	c_037_04	0.426	4.62	404	SL	II	45.9	N/A	76.2	90	60
101	McDonald	c_051_02	0.331	3.83	466	SL	II	46.1	N/A	76.2	90	50
102	McDonald	c_051_04	0.331	3.83	466	SL	II	46.1	N/A	76.2	90	50
103	McDonald	c_051_10	0.425	4.65	404	SL	II	51.2	N/A	76.2	90	50
104	McDonald	c_051_12	0.425	4.65	404	SL	II	51.2	N/A	76.2	90	50
105	McDonald	c_051_16	0.434	3.67	460	SL	II	46.1	N/A	76.2	90	50
106	Takahashi	c_066_02	0.4	4.45	400	SL	II	57.1		45	100	75
107	Takahashi	c_066_04	0.4	4.45	400	SL	II	56.6		45	30	75
108	Keeton	c_015_02	0.46	3.73	452	RS	III	45.2	25860	38	8	75
109	Keeton	c_015_03	0.46	3.73	452	RS	III	45.2	25860	38	8	50
110	Keeton	c_015_06	0.46	3.73	452	RS	III	45.2	25860	76	8	75
111	Keeton	c_015_07	0.46	3.73	452	RS	III	45.2	25860	76	8	50
112	Rüsch	c_030_01	0.49	5.34	344	RS	III	48.6	N/A	60	29	65
113	Lambotte	c_058_13	0.43	3.91	450	RS	III	43.2	N/A	75	28	60

Set No.	Author Name	File No.	w/c	a/c	c	Type European	Type American	$f'_{c(28)}$	$E_{c(28)}$	D	t_o	H
114	Wischers	c_061_09	0.48	5.86	325	RS	III	60.4	N/A	75	28	65
115	Wischers	c_061_11	0.48	4.24	410	RS	III	54.5	N/A	75	23	65
116	Wischers	c_061_12	0.48	4.24	410	RS	III	54.5	N/A	75	28	65
117	Wischers	c_061_15	0.4	4.53	400	RS	III	64.6	N/A	75	28	65
118	Wesche	c_063_11	0.55	5.40	337	RS	III	46.5	37500	100	7	65
119	Wesche	c_063_12	0.55	5.40	337	RS	III	46.5	37500	100	28	65
120	Yue	c_089_01	0.323	4.88	400	RS	III	80.5	N/A	75	28	60
121	Yue	c_089_02	0.323	4.88	400	RS	III	80.5	N/A	75	28	60
122	Hilsdorf	c_091_03	0.55	5.40	337	RS	III	40.3	30200	100	7	65
123	Hilsdorf	c_091_04	0.55	5.40	337	RS	III	40.3	30200	100	28	65
124	Hilsdorf	c_091_05	0.55	5.40	337	RS	III	40.3	30200	100	90	65
125	Hilsdorf	c_091_07	0.55	5.40	337	RS	III	40.3	30200	100	7	65
126	Hilsdorf	c_091_08	0.55	5.40	337	RS	III	40.3	30200	100	28	65
127	Hilsdorf	c_091_09	0.55	5.40	337	RS	III	40.3	30200	100	90	65

w/c = Water-to-cement ratio

a/c = Aggregate-to-cement ratio

c = Cement content in kg/m^3

Type = Type of cement

$f'_{c(28)}$ = 28-day mean cylindrical concrete compressive strength in MPa

$E_{c(28)}$ = 28-day modulus of elasticity in MPa

D = 2Ac/U = Area of member to its perimeter ratio

t_o = Age of concrete at loading

Note: Data sets in Appendix V is grouped according to type of cement

Appendix VI: Shrinkage Experimental Data Points from the RILEM Data Bank Utilized in this Study

File No.	Days	Experimental (microstrain)
e_011_05	1	20
e_011_05	3	30
e_011_05	7	70
e_011_05	10	90
e_011_05	21	135
e_011_05	28	155
e_011_05	49	185
e_011_05	52	200
e_011_05	77	250
e_011_05	90	265
e_011_05	116	315
e_011_05	174	375
e_011_05	266	435
e_011_05	356	460
e_011_05	536	480
e_011_05	710	480
e_011_05	744	450
e_011_05	1124	480
e_011_05	1455	520
e_030_02	4	45
e_030_02	11	95
e_030_02	21	150
e_030_02	37	205
e_030_02	63	250
e_030_02	113	310
e_030_02	173	350
e_030_02	273	390
e_030_02	433	440
e_030_02	693	460
e_030_02	1093	490
e_030_03	4	60
e_030_03	11	130
e_030_03	21	205
e_030_03	37	260
e_030_03	63	315
e_030_03	113	370
e_030_03	173	415
e_030_03	273	450
e_030_03	433	470
e_030_03	693	480
e_061_02	3	15
e_061_02	7	48
e_061_02	28	172
e_061_02	91	298
e_061_02	182	357
e_061_02	365	394

File No.	Days	Experimental (microstrain)
e_091_03	4	53
e_091_03	8	90
e_091_03	14	125
e_091_03	21	159
e_091_03	28	183
e_091_03	36	208
e_091_03	49	233
e_091_03	63	250
e_091_03	83	290
e_091_03	97	308
e_091_03	113	325
e_091_03	138	347
e_091_03	173	369
e_091_03	203	388
e_091_03	263	415
e_091_03	358	442
e_091_03	493	475
e_091_03	723	510
e_091_03	1088	545
e_091_04	7	105
e_091_04	15	152
e_091_04	28	195
e_091_04	42	229
e_091_04	62	262
e_091_04	76	286
e_091_04	92	308
e_091_04	117	332
e_091_04	152	358
e_091_04	182	378
e_091_04	242	408
e_091_04	337	442
e_091_04	472	470
e_091_04	702	504
e_091_04	1067	540
e_091_05	5	68
e_091_05	14	119
e_091_05	22	148
e_091_05	30	170
e_091_05	43	195
e_091_05	55	217
e_091_05	90	257
e_091_05	120	285
e_091_05	180	322
e_091_05	275	357
e_091_05	410	394
e_091_05	640	428

File No.	Days	Experimental (microstrain)
e_061_02	730	421
e_061_02	1095	435
e_061_02	1460	443
e_061_02	1825	450
e_061_02	2190	455
e_061_03	7	40
e_061_03	28	159
e_061_03	91	292
e_061_03	182	351
e_061_03	365	384
e_061_03	730	413
e_061_03	1095	424
e_061_03	1460	430
e_061_03	1825	436
e_061_03	2190	440
e_061_05	1	24
e_061_05	3	61
e_061_05	7	81
e_061_05	28	240
e_061_05	91	381
e_061_05	182	447
e_061_05	365	484
e_061_05	730	514
e_061_05	1095	529
e_061_05	1460	527
e_061_05	1825	542
e_061_05	2190	545
e_061_06	1	6
e_061_06	3	27
e_061_06	7	77
e_061_06	28	228
e_061_06	91	382
e_061_06	182	469
e_061_06	365	498
e_061_06	730	538
e_061_06	1095	557
e_061_06	1460	561
e_061_06	1825	582
e_061_06	2190	575
e_063_02	1	5
e_063_02	2	15
e_063_02	3	15
e_063_02	4	27
e_063_02	7	50
e_063_02	10	63
e_063_02	14	85
e_063_02	21	120
e_063_02	28	144
e_063_02	42	185
e_063_02	56	217
e_063_02	71	243

File No.	Days	Experimental (microstrain)
e_091_05	1005	453
e_091_05	1370	470
e_091_05	1735	478
e_022_01	1	50
e_022_01	2	79
e_022_01	3	102
e_022_01	6	168
e_022_01	7	188
e_022_01	14	288
e_022_01	21	350
e_022_01	28	388
e_022_01	43	449
e_022_01	56	478
e_022_01	70	506
e_022_01	84	517
e_022_01	98	545
e_022_01	120	558
e_022_01	157	565
e_022_02	1	40
e_022_02	2	61
e_022_02	3	91
e_022_02	6	139
e_022_02	7	158
e_022_02	14	238
e_022_02	21	308
e_022_02	28	338
e_022_02	43	408
e_022_02	56	449
e_022_02	70	467
e_022_02	84	488
e_022_02	98	518
e_022_02	120	528
e_022_02	157	539
e_022_03	1	17
e_022_03	2	38
e_022_03	3	59
e_022_03	6	99
e_022_03	7	108
e_022_03	14	190
e_022_03	21	218
e_022_03	28	289
e_022_03	43	347
e_022_03	56	408
e_022_03	70	438
e_022_03	84	458
e_022_03	98	487
e_022_03	120	496
e_022_03	157	528
e_022_04	1	58
e_022_04	2	79
e_022_04	3	109

File No.	Days	Experimental (microstrain)
e_063_02	91	275
e_063_02	105	291
e_063_02	182	362
e_063_02	273	412
e_063_02	364	432
e_063_02	457	445
e_063_02	549	452
e_072_06	12.5	220
e_072_06	25	290
e_072_06	37.5	360
e_072_06	50	395
e_072_06	62.5	425
e_072_06	75	440
e_072_06	87.5	450
e_072_06	100	470
e_072_06	112.5	480
e_072_06	125	490
e_072_06	137.5	500
e_072_06	150	500
e_072_06	162.5	510
e_072_06	175	515
e_072_06	187.5	520
e_072_06	200	530
e_072_06	212.5	535
e_072_06	225	535
e_072_06	237.5	535
e_072_06	250	540
e_072_06	262.5	540
e_072_06	275	540
e_072_06	287.5	540
e_072_06	300	540
e_072_06	312.5	550
e_072_06	325	550
e_072_06	337.5	550
e_072_06	350	530
e_072_08	12.5	370
e_072_08	25	460
e_072_08	37.5	520
e_072_08	50	560
e_072_08	62.5	590
e_072_08	75	610
e_072_08	87.5	635
e_072_08	100	640
e_072_08	112.5	660
e_072_08	125	665
e_072_08	137.5	675
e_072_08	150	680
e_072_08	162.5	690
e_072_08	175	690
e_072_08	187.5	700
e_072_08	200	705

File No.	Days	Experimental (microstrain)
e_022_04	4	129
e_022_04	6	170
e_022_04	14	280
e_022_04	21	339
e_022_04	28	379
e_022_04	43	428
e_022_04	48	438
e_022_04	56	477
e_022_04	70	495
e_022_04	84	515
e_022_04	98	556
e_022_04	120	566
e_022_04	157	576
e_022_05	1	37
e_022_05	2	58
e_022_05	3	79
e_022_05	4	89
e_022_05	6	118
e_022_05	14	208
e_022_05	21	267
e_022_05	28	307
e_022_05	43	356
e_022_05	56	418
e_022_05	70	426
e_022_05	84	477
e_022_05	98	495
e_022_05	120	505
e_022_05	157	525
e_022_06	1	30
e_022_06	2	50
e_022_06	4	79
e_022_06	6	99
e_022_06	7	110
e_022_06	14	145
e_022_06	21	228
e_022_06	28	259
e_022_06	43	307
e_022_06	56	368
e_022_06	70	400
e_022_06	84	426
e_022_06	98	455
e_022_06	120	465
e_022_06	157	484
e_078_01	2	77
e_078_01	3	100
e_078_01	4	121
e_078_01	7	178
e_078_01	8	205
e_078_01	14	280
e_078_01	24	390
e_078_01	25	400

File No.	Days	Experimental (microstrain)
e_072_08	212.5	710
e_072_08	225	715
e_072_08	237.5	720
e_072_08	250	720
e_072_08	262.5	720
e_072_08	275	725
e_072_08	287.5	725
e_072_08	300	725
e_072_08	312.5	730
e_072_08	325	730
e_072_08	337.5	735
e_072_09	12.5	280
e_072_09	25	370
e_072_09	37.5	420
e_072_09	50	440
e_072_09	62.5	480
e_072_09	75	490
e_072_09	87.5	510
e_072_09	100	520
e_072_09	112.5	530
e_072_09	125	535
e_072_09	137.5	550
e_072_09	150	555
e_072_09	162.5	560
e_072_09	175	560
e_072_09	187.5	570
e_072_09	200	570
e_072_09	212.5	570
e_072_09	225	575
e_072_09	237.5	578
e_072_09	250	580
e_072_09	262.5	580
e_072_09	275	580
e_072_09	287.5	585
e_072_09	300	590
e_072_09	312.5	590
e_072_09	325	590
e_072_09	337.5	590
e_072_10	12.5	280
e_072_10	25	370
e_072_10	37.5	440
e_072_10	50	480
e_072_10	62.5	490
e_072_10	75	520
e_072_10	87.5	540
e_072_10	100	550
e_072_10	112.5	560
e_072_10	125	570
e_072_10	137.5	575
e_072_10	150	580
e_072_10	162.5	590

File No.	Days	Experimental (microstrain)
e_078_01	29	436
e_078_01	35	453
e_078_01	42	513
e_078_01	49	502
e_078_01	57	511
e_078_01	64	525
e_078_01	73	548
e_078_01	95	568
e_078_01	115	598
e_078_01	135	577
e_078_01	157	583
e_078_01	183	590
e_078_01	205	581
e_078_01	218	573
e_078_01	245	610
e_078_01	338	595
e_078_01	438	620
e_078_01	543	623
e_078_01	743	656
e_078_01	920	651
e_078_01	1122	675
e_078_01	1331	665
e_078_01	1473	682
e_078_01	3823	719
e_078_01	4321	758
e_078_01	5169	725
e_078_01	6342	733
e_078_02	1	44
e_078_02	2	70
e_078_02	3	95
e_078_02	6	154
e_078_02	10	202
e_078_02	21	309
e_078_02	28	359
e_078_02	35	405
e_078_02	42	437
e_078_02	49	463
e_078_02	62	504
e_078_02	76	545
e_078_02	128	603
e_078_02	164	625
e_078_02	190	650
e_078_02	227	667
e_078_02	329	663
e_078_02	377	692
e_078_02	441	705
e_078_02	478	753
e_078_02	521	741
e_078_02	542	732
e_078_02	552	741
e_078_02	563	748

File No.	Days	Experimental (microstrain)
e_072_10	175	595
e_072_10	187.5	600
e_072_10	200	605
e_072_10	212.5	610
e_072_10	225	613
e_072_10	237.5	615
e_072_10	250	620
e_072_10	262.5	622
e_072_10	275	620
e_072_10	287.5	620
e_072_10	300	620
e_072_10	312.5	620
e_072_10	325	620
e_072_10	337.5	620
e_079_01	1	53
e_079_01	3	94
e_079_01	6	160
e_079_01	7	176
e_079_01	9	208
e_079_01	13	265
e_079_01	20	350
e_079_01	34	443
e_079_01	55	522
e_079_01	76	557
e_079_01	104	595
e_079_01	132	615
e_079_01	174	622
e_079_01	204	642
e_079_01	244	652
e_079_01	295	660
e_079_01	384	695
e_079_01	514	700
e_079_01	687	714
e_079_01	1935	732
e_079_01	3492	740
e_079_02	1	47
e_079_02	3	77
e_079_02	6	125
e_079_02	7	135
e_079_02	9	160
e_079_02	13	202
e_079_02	20	260
e_079_02	34	372
e_079_02	55	452
e_079_02	76	515
e_079_02	104	560
e_079_02	132	589
e_079_02	174	610
e_079_02	204	628
e_079_02	244	650
e_079_02	295	664

File No.	Days	Experimental (microstrain)
e_078_02	653	720
e_078_02	667	712
e_078_02	694	725
e_078_02	785	717
e_078_02	990	747
e_078_02	1190	770
e_078_02	1569	799
e_078_02	1778	777
e_078_02	1920	788
e_078_02	4270	800
e_078_02	4768	832
e_078_02	5616	785
e_078_02	6789	772
e_083_01	0.2	35
e_083_01	1	61
e_083_01	2	92
e_083_01	3	115
e_083_01	6	162
e_083_01	8	187
e_083_01	14	245
e_083_01	21	282
e_083_01	34	351
e_083_01	52	427
e_083_01	91	485
e_083_01	169	541
e_083_01	258	629
e_083_01	412	676
e_083_01	554	702
e_083_01	1105	720
e_083_02	0.2	26
e_083_02	1	44
e_083_02	2	59
e_083_02	3	72
e_083_02	6	102
e_083_02	8	119
e_083_02	14	161
e_083_02	21	186
e_083_02	34	237
e_083_02	52	293
e_083_02	91	366
e_083_02	169	443
e_083_02	258	533
e_083_02	412	607
e_083_02	554	652
e_083_02	1105	663
e_083_03	0.2	23
e_083_03	0.9	30
e_083_03	2	39
e_083_03	3	42
e_083_03	6	56
e_083_03	8	63

File No.	Days	Experimental (microstrain)
e_079_02	384	682
e_079_02	514	702
e_079_02	687	716
e_079_02	1935	735
e_079_02	3492	719
e_079_03	1	46
e_079_03	3	64
e_079_03	6	99
e_079_03	7	105
e_079_03	9	121
e_079_03	13	151
e_079_03	20	200
e_079_03	34	282
e_079_03	55	368
e_079_03	76	423
e_079_03	104	481
e_079_03	132	521
e_079_03	174	544
e_079_03	204	575
e_079_03	244	589
e_079_03	295	600
e_079_03	384	628
e_079_03	514	649
e_079_03	687	669
e_079_03	1935	697
e_079_03	3492	686
e_079_04	1	24
e_079_04	3	28
e_079_04	6	32
e_079_04	7	40
e_079_04	9	51
e_079_04	13	75
e_079_04	20	97
e_079_04	34	165
e_079_04	55	220
e_079_04	76	278
e_079_04	104	317
e_079_04	132	342
e_079_04	174	399
e_079_04	204	432
e_079_04	244	460
e_079_04	295	479
e_079_04	384	519
e_079_04	514	538
e_079_04	687	567
e_079_04	1935	602
e_079_04	3492	596
e_079_05	1	16
e_079_05	3	11
e_079_05	6	23
e_079_05	7	28

File No.	Days	Experimental (microstrain)
e_083_03	14	82
e_083_03	21	105
e_083_03	34	129
e_083_03	52	156
e_083_03	91	197
e_083_03	169	274
e_083_03	258	340
e_083_03	412	412
e_083_03	554	465
e_083_03	1105	535
e_037_01	2	0.4
e_037_01	5	2
e_037_01	7	4.4
e_037_01	14	5.9
e_037_01	21	8.5
e_037_01	28	9.4
e_037_01	56	14.7
e_037_01	84	18.5
e_037_01	112	23.9
e_037_01	140	26.4
e_037_01	168	28.9
e_037_01	196	31.4
e_037_01	224	32.2
e_037_01	252	32.1
e_037_01	280	33.7
e_037_01	308	33.7
e_037_01	336	34.5
e_037_01	364	35
e_037_01	366	34.8
e_037_01	371	35.6
e_037_01	378	35.8
e_037_01	385	35.5
e_037_01	392	36
e_051_03	1	0.7
e_051_03	2	1
e_051_03	3	1
e_051_03	5	2
e_051_03	6	3.5
e_051_03	9	4.5
e_051_03	22	8.3
e_051_03	27	9.5
e_051_03	44	13
e_051_03	55	15
e_051_03	77	18
e_051_03	92	19.7
e_051_03	120	22.3
e_051_03	169	25.3
e_051_03	197	28
e_051_03	229	27.5
e_051_03	254	29.7
e_051_03	286	29.3

File No.	Days	Experimental (microstrain)
e_079_05	9	38
e_079_05	13	48
e_079_05	20	74
e_079_05	34	95
e_079_05	55	148
e_079_05	76	192
e_079_05	104	235
e_079_05	132	269
e_079_05	174	325
e_079_05	204	338
e_079_05	244	377
e_079_05	295	402
e_079_05	384	455
e_079_05	514	485
e_079_05	687	529
e_079_05	1935	594
e_079_05	3492	585
e_081_07	7	90
e_081_07	14	180
e_081_07	20	205
e_081_07	28	237
e_081_07	44	280
e_081_07	80	375
e_081_07	105	385
e_081_07	139	390
e_081_07	166	400
e_081_07	195	380
e_081_07	225	385
e_081_07	258	400
e_081_07	288	380
e_081_07	320	380
e_081_07	360	388
e_081_08	7	112
e_081_08	14	195
e_081_08	20	230
e_081_08	28	270
e_081_08	44	325
e_081_08	80	355
e_081_08	105	385
e_081_08	139	435
e_081_08	166	470
e_081_08	195	462
e_081_08	225	450
e_081_08	258	465
e_081_08	288	445
e_081_08	320	465
e_081_08	360	485
e_088_02	2	8.3
e_088_02	8	23.3
e_088_02	9	31.7
e_088_02	9	36.7

File No.	Days	Experimental (microstrain)
e_051_03	314	31
e_051_03	363	31.3
e_051_03	373	30.7
e_051_03	397	31.3
e_051_03	418	32.3
e_051_03	440	31.7
e_051_03	466	31.7
e_051_03	487	31.3
e_051_07	1	0.5
e_051_07	2	0.5
e_051_07	6	6
e_051_07	8	12
e_051_07	29	25
e_051_07	64	41.7
e_051_07	79	42
e_051_07	97	48
e_051_07	159	57.7
e_051_07	216	65
e_051_07	249	66
e_051_07	306	68.7
e_051_07	347	70.7
e_051_07	365	71.3
e_051_07	373	71
e_051_07	392	75
e_051_07	424	77.7
e_051_07	467	76
e_051_07	482	76.3
e_051_11	1	3.5
e_051_11	2	6
e_051_11	10	23.5
e_051_11	27	48.5
e_051_11	38	56.5
e_051_11	104	79
e_051_11	141	90
e_051_11	181	96
e_051_11	198	97.5
e_051_11	295	117.5
e_051_11	440	141
e_051_11	458	143
e_051_11	484	152
e_015_02	1	140
e_015_02	7	390
e_015_02	14	520
e_015_02	21	605
e_015_02	28	660
e_015_02	56	790
e_015_02	91	865
e_015_02	175	945
e_015_02	365	1010
e_015_02	897	1055
e_015_03	1	105

File No.	Days	Experimental (microstrain)
e_088_02	20	63.3
e_088_02	26	95
e_088_02	30	90
e_088_02	33	86.7
e_088_02	35	111.7
e_088_02	54	105
e_088_02	82	116.7
e_088_02	105	116.7
e_088_02	110	113.3
e_088_02	145	145
e_088_02	162	178.3
e_088_02	210	188.3
e_088_02	236	158.3
e_088_06	2	8.3
e_088_06	3	45
e_088_06	4	70
e_088_06	8	51.7
e_088_06	8	48.3
e_088_06	14	55
e_088_06	18	80
e_088_06	21	98.3
e_088_06	23	103.3
e_088_06	42	110
e_088_06	58	103.3
e_088_06	70	145
e_088_06	93	153.3
e_088_06	98	153.3
e_088_06	133	153.3
e_088_06	150	156.7
e_088_06	224	193.3
e_088_06	238	203.3
e_011_01	1	5
e_011_01	4	5
e_011_01	7	50
e_011_01	10	75
e_011_01	21	115
e_011_01	28	130
e_011_01	49	175
e_011_01	52	155
e_011_01	77	200
e_011_01	90	210
e_011_01	116	255
e_011_01	176	300
e_011_01	264	365
e_011_01	356	385
e_011_01	536	400
e_011_01	745	385
e_011_01	1126	415
e_011_01	1599	430
e_011_02	7	45
e_011_02	21	85

File No.	Days	Experimental (microstrain)
e_015_03	7	310
e_015_03	14	410
e_015_03	21	475
e_015_03	28	520
e_015_03	56	610
e_015_03	91	670
e_015_03	175	725
e_015_03	365	755
e_015_03	897	775
e_015_07	1	125
e_015_07	7	330
e_015_07	14	445
e_015_07	21	525
e_015_07	28	580
e_015_07	56	715
e_015_07	91	805
e_015_07	175	905
e_015_07	365	975
e_015_07	897	1030
e_015_08	1	90
e_015_08	7	255
e_015_08	14	340
e_015_08	21	400
e_015_08	28	440
e_015_08	56	535
e_015_08	91	600
e_015_08	175	660
e_015_08	365	710
e_015_08	897	745
e_015_10	1	90
e_015_10	7	220
e_015_10	14	305
e_015_10	21	365
e_015_10	28	415
e_015_10	56	540
e_015_10	91	640
e_015_10	175	765
e_015_10	365	885
e_015_10	897	965
e_015_11	1	75
e_015_11	7	185
e_015_11	14	240
e_015_11	21	285
e_015_11	28	315
e_015_11	56	410
e_015_11	91	485
e_015_11	175	570
e_015_11	365	625
e_015_11	897	655
e_015_16	7	165
e_015_16	28	290

File No.	Days	Experimental (microstrain)
e_011_02	24	100
e_011_02	28	115
e_011_02	35	120
e_011_02	49	135
e_011_02	77	175
e_011_02	83	180
e_011_02	111	210
e_011_02	142	210
e_011_02	171	235
e_011_02	201	245
e_011_02	263	255
e_011_02	353	275
e_011_02	535	290
e_011_02	748	280
e_011_02	962	305
e_011_02	1099	295
e_011_02	1440	325
e_011_03	7	15
e_011_03	21	85
e_011_03	22	80
e_011_03	28	90
e_011_03	35	100
e_011_03	49	110
e_011_03	77	150
e_011_03	83	175
e_011_03	111	200
e_011_03	141	210
e_011_03	171	215
e_011_03	202	255
e_011_03	291	260
e_011_03	353	285
e_011_03	533	300
e_011_03	755	275
e_011_03	969	305
e_011_03	1106	290
e_011_03	1447	340
e_014_01	2	7
e_014_01	5	9
e_014_01	9	18
e_014_01	13	28
e_014_01	20	44
e_014_01	26	75
e_014_01	49	137
e_014_01	57	145
e_014_01	74	180
e_014_01	89	183
e_014_01	113	208
e_014_01	174	257
e_014_01	204	280
e_014_01	258	317
e_014_01	363	315

File No.	Days	Experimental (microstrain)
e_015_16	56	380
e_015_16	91	450
e_015_16	175	545
e_015_16	365	615
e_015_17	7	160
e_015_17	28	265
e_015_17	56	330
e_015_17	91	375
e_015_17	175	415
e_015_17	365	450
e_015_18	7	195
e_015_18	28	265
e_015_18	56	315
e_015_18	91	350
e_015_18	175	400
e_015_18	365	435
e_015_22	1	100
e_015_22	7	330
e_015_22	28	570
e_015_22	56	695
e_015_22	91	785
e_015_22	175	885
e_015_22	365	935
e_015_23	1	120
e_015_23	7	415
e_015_23	28	660
e_015_23	56	775
e_015_23	91	845
e_015_23	175	910
e_015_23	365	970
e_015_23	730	1015
e_015_24	1	70
e_015_24	7	305
e_015_24	28	525
e_015_24	56	650
e_015_24	91	740
e_015_24	175	850
e_015_24	365	925
e_015_24	730	960
e_015_25	1	35
e_015_25	7	180
e_015_25	28	325
e_015_25	56	415
e_015_25	91	495
e_015_25	175	605
e_015_25	365	720
e_015_25	730	795
e_015_26	1	20
e_015_26	7	100
e_015_26	28	180
e_015_26	56	230

File No.	Days	Experimental (microstrain)
e_014_01	441	327
e_014_01	623	348
e_014_01	916	374
e_014_01	1031	360
e_014_02	2	18
e_014_02	5	18
e_014_02	10	21
e_014_02	17	44
e_014_02	21	59
e_014_02	31	64
e_014_02	50	85
e_014_02	60	93
e_014_02	72	107
e_014_02	95	137
e_014_02	126	159
e_014_02	186	189
e_014_02	219	201
e_014_02	270	204
e_014_02	345	214
e_014_02	463	240
e_014_02	569	248
e_014_02	862	296
e_014_02	1079	313
e_014_03	6	62
e_014_03	8	59
e_014_03	15	88
e_014_03	20	110
e_014_03	27	137
e_014_03	37	142
e_014_03	47	182
e_014_03	63	216
e_014_03	78	245
e_014_03	93	286
e_014_03	121	317
e_014_03	175	359
e_014_03	222	357
e_014_03	254	367
e_014_03	345	389
e_014_03	477	433
e_014_03	558	437
e_014_03	844	481
e_014_03	1064	498
e_014_05	1	20
e_014_05	2	59
e_014_05	9	88
e_014_05	22	148
e_014_05	27	176
e_014_05	42	239
e_014_05	58	294
e_014_05	68	304
e_014_05	77	311
e_015_26	91	275
e_015_26	175	365
e_015_26	365	490
e_015_26	730	545
e_015_27	1	15
e_015_27	7	90
e_015_27	28	150
e_015_27	56	195
e_015_27	91	240
e_015_27	175	315
e_015_27	365	435
e_015_27	720	490
e_020_01	8	240
e_020_01	10	330
e_020_01	17	460
e_020_01	31	580
e_020_01	48	660
e_020_01	63	705
e_020_01	89	740
e_020_01	120	775
e_020_01	185	810
e_020_01	248	840
e_020_01	363	860
e_020_01	412	870
e_020_01	538	895
e_020_01	766	900
e_020_01	849	910
e_020_01	1035	920
e_020_01	1340	925
e_020_01	1395	930
e_020_01	1495	930
e_020_02	16	300
e_020_02	28	380
e_020_02	31	440
e_020_02	41	470
e_020_02	55	545
e_020_02	80	605
e_020_02	120	660
e_020_02	142	710
e_020_02	181	750
e_020_02	298	840
e_020_02	385	850
e_020_02	454	850
e_020_02	568	860
e_020_02	680	880
e_020_02	875	885
e_020_02	1110	890
e_020_02	1430	900
e_020_02	1633	880
e_020_02	1760	890
e_020_03	12	180

File No.	Days	Experimental (microstrain)
e_014_05	86	320
e_014_05	126	322
e_014_05	160	322
e_014_05	198	348
e_014_05	231	379
e_014_05	282	410
e_014_05	414	414
e_014_05	531	451
e_014_05	783	498
e_014_05	1002	536
e_063_07	1	3
e_063_07	3	9
e_063_07	5	15
e_063_07	7	21
e_063_07	18	54
e_063_07	26	77
e_063_07	42	120
e_063_07	63	171
e_063_07	124	272
e_063_07	185	333
e_063_07	277	387
e_063_07	368	419
e_063_07	461	435
e_063_07	559	449
e_063_07	639	458
e_063_07	727	464
e_063_07	786	467
e_063_07	817	470
e_063_07	849	474
e_063_08	1	10
e_063_08	3	25
e_063_08	7	44
e_063_08	10	60
e_063_08	14	84
e_063_08	20	100
e_063_08	28	125
e_063_08	42	161
e_063_08	56	200
e_063_08	70	219
e_063_08	98	266
e_063_08	120	297
e_063_08	175	355
e_063_08	220	391
e_063_08	273	423
e_063_08	357	452
e_063_08	581	486
e_063_08	728	492
e_063_08	791	492
e_063_09	1	5
e_063_09	3	30
e_063_09	7	60

File No.	Days	Experimental (microstrain)
e_020_03	25	290
e_020_03	45	410
e_020_03	65	490
e_020_03	85	530
e_020_03	115	570
e_020_03	140	600
e_020_03	175	630
e_020_03	260	690
e_020_03	350	710
e_020_03	445	730
e_020_03	560	750
e_020_03	672	755
e_020_03	800	775
e_020_03	1110	785
e_020_03	1300	800
e_020_03	1518	795
e_020_03	1695	795
e_020_03	1795	800
e_020_04	15	110
e_020_04	25	220
e_020_04	33	260
e_020_04	45	310
e_020_04	60	350
e_020_04	92	410
e_020_04	145	505
e_020_04	180	550
e_020_04	277	620
e_020_04	370	630
e_020_04	435	640
e_020_04	545	670
e_020_04	735	680
e_020_04	910	690
e_020_04	1020	700
e_020_04	1110	710
e_020_04	1410	720
e_020_04	1680	710
e_020_04	1750	715
e_020_05	15	80
e_020_05	24	150
e_020_05	28	175
e_020_05	43	200
e_020_05	55	225
e_020_05	66	245
e_020_05	80	260
e_020_05	95	285
e_020_05	138	335
e_020_05	185	365
e_020_05	310	455
e_020_05	365	465
e_020_05	512	520
e_020_05	756	560

File No.	Days	Experimental (microstrain)
e_063_09	9	72
e_063_09	14	104
e_063_09	20	120
e_063_09	26	136
e_063_09	41	198
e_063_09	54	230
e_063_09	68	259
e_063_09	89	291
e_063_09	126	335
e_063_09	182	378
e_063_09	272	433
e_063_09	355	467
e_063_09	551	504
e_063_09	663	518
e_063_09	761	527
e_063_09	789	530
e_067_01	7	18
e_067_01	21	53
e_067_01	42	98
e_067_01	111	143
e_067_01	142	195
e_067_01	163	205
e_067_01	174	213
e_067_01	212	216
e_067_01	233	220
e_067_01	272	225
e_067_01	306	228
e_067_01	438	231
e_067_01	540	235
e_069_03	2	4
e_069_03	7	50
e_069_03	22	167
e_069_03	30	195
e_069_03	51	257
e_069_03	120	344
e_069_03	177	375
e_069_03	259	406
e_069_03	328	418
e_069_03	524	450
e_069_03	725	469
e_088_20	7	92.5
e_088_20	19	152.5
e_088_20	40	205.8
e_088_20	47	229.2
e_088_20	82	269.2
e_088_20	99	265.8
e_088_20	173	307.5
e_088_20	209	332.5
e_088_20	236	310.8
e_088_20	294	332.5
e_030_07	4	110

File No.	Days	Experimental (microstrain)
e_020_05	1070	580
e_020_05	1160	590
e_020_05	1375	610
e_020_05	1648	605
e_020_05	1720	610
e_020_06	28	110
e_020_06	40	155
e_020_06	52	180
e_020_06	65	210
e_020_06	88	230
e_020_06	120	260
e_020_06	195	340
e_020_06	265	400
e_020_06	375	440
e_020_06	440	460
e_020_06	505	480
e_020_06	595	490
e_020_06	720	520
e_020_06	1005	540
e_020_06	1090	550
e_020_06	1270	565
e_020_06	1395	580
e_020_06	1560	570
e_020_06	1775	585
e_020_07	20	40
e_020_07	38	80
e_020_07	55	110
e_020_07	70	120
e_020_07	95	160
e_020_07	117	170
e_020_07	150	210
e_020_07	210	255
e_020_07	280	290
e_020_07	328	305
e_020_07	395	320
e_020_07	460	330
e_020_07	580	350
e_020_07	750	410
e_020_07	875	400
e_020_07	1065	420
e_020_07	1250	435
e_020_07	1530	450
e_020_07	1745	470
e_020_08	9	60
e_020_08	18	90
e_020_08	28	120
e_020_08	56	190
e_020_08	82	230
e_020_08	110	255
e_020_08	176	340
e_020_08	266	385

File No.	Days	Experimental (microstrain)
e_030_07	11	220
e_030_07	21	320
e_030_07	37	410
e_030_07	63	470
e_030_07	113	530
e_030_07	173	560
e_030_07	273	600
e_030_07	433	620
e_030_07	693	630
e_061_09	3	28
e_061_09	7	93
e_061_09	28	211
e_061_09	91	331
e_061_09	182	392
e_061_09	365	432
e_061_09	730	456
e_061_09	1095	469
e_061_09	1460	474
e_061_09	1825	464
e_061_09	2190	479
e_061_12	1	2
e_061_12	3	40
e_061_12	7	90
e_061_12	28	234
e_061_12	91	378
e_061_12	182	456
e_061_12	365	506
e_061_12	730	547
e_061_12	1095	567
e_061_12	1460	576
e_061_12	1825	578
e_061_12	2190	593
e_061_15	1	1
e_061_15	3	10
e_061_15	7	46
e_061_15	28	141
e_061_15	91	215
e_061_15	182	255
e_061_15	365	303
e_061_15	730	328
e_061_15	1095	332
e_061_15	1460	336
e_061_15	1825	340
e_061_15	2190	344
e_063_05	1	8
e_063_05	4	34
e_063_05	6	50
e_063_05	11	58
e_063_05	14	71
e_063_05	19	100
e_063_05	27	134

File No.	Days	Experimental (microstrain)
e_020_08	364	410
e_020_08	425	440
e_020_08	540	460
e_020_08	590	480
e_020_08	785	505
e_020_08	1025	520
e_020_08	1128	530
e_020_08	1335	540
e_020_08	1522	550
e_020_08	1610	550
e_020_08	1705	560
e_020_09	10	45
e_020_09	18	195
e_020_09	28	290
e_020_09	60	410
e_020_09	84	480
e_020_09	110	515
e_020_09	140	550
e_020_09	178	575
e_020_09	270	615
e_020_09	365	625
e_020_09	542	660
e_020_09	720	680
e_020_09	946	685
e_020_09	1130	680
e_020_09	1223	695
e_020_09	1442	705
e_020_09	1555	700
e_020_09	1625	705
e_020_09	1690	700
e_020_10	8	185
e_020_10	10	270
e_020_10	16	360
e_020_10	23	400
e_020_10	32	470
e_020_10	46	530
e_020_10	63	565
e_020_10	74	595
e_020_10	108	640
e_020_10	176	685
e_020_10	256	695
e_020_10	360	710
e_020_10	526	750
e_020_10	774	745
e_020_10	1052	745
e_020_10	1276	760
e_020_10	1496	760
e_020_10	1552	765
e_020_10	1622	765
e_063_05	275	467
e_063_05	306	490

File No.	Days	Experimental (microstrain)
e_063_05	40	179
e_063_05	54	216
e_063_05	67	245
e_063_05	89	285
e_063_05	118	326
e_063_05	174	387

File No.	Days	Experimental (microstrain)
e_063_05	369	522
e_063_05	551	580
e_063_05	705	611
e_063_05	760	620

Appendix VII: Creep Experimental Data Points from the RILEM Data Bank Utilized in this Study

File No.	Days	Experimental (microstrain/MPa)
c_001_01	40	57.0
c_001_01	161	83.0
c_001_01	241	92.0
c_001_01	300	96.0
c_001_01	700	111.0
c_001_01	900	112.0
c_001_02	40	60.0
c_001_02	100	78.0
c_001_02	161	93.0
c_001_02	241	102.0
c_001_02	300	105.0
c_001_02	400	112.0
c_001_02	550	115.0
c_001_02	700	120.0
c_001_02	900	124.0
c_001_05	40	44.0
c_001_05	82	55.0
c_001_05	100	58.0
c_001_05	160	64.0
c_001_05	400	78.0
c_001_05	552	83.0
c_001_05	700	85.0
c_001_05	900	87.0
c_001_06	23	50.0
c_001_06	40	64.0
c_001_06	82	85.0
c_001_06	120	104.0
c_001_06	160	113.0
c_001_06	240	120.0
c_001_06	320	125.0
c_001_06	400	129.0
c_001_06	548	135.0
c_001_06	700	140.0
c_001_06	900	142.0
c_006_07	1	38.0
c_006_07	3	47.0
c_006_07	7	51.0
c_006_07	14	55.0
c_006_07	28	58.0
c_006_07	55	65.0
c_006_07	85	69.0
c_006_07	180	76.0
c_006_07	269	78.0
c_006_07	375	78.0
c_006_07	569	82.0
c_006_07	767	89.0

File No.	Days	Experimental (microstrain/MPa)
c_079_15	1	46.4
c_079_15	3	50.7
c_079_15	7	56.4
c_079_15	14	64.1
c_079_15	28	70.0
c_079_15	49	79.0
c_079_15	70	85.6
c_079_15	98	92.4
c_079_15	126	96.7
c_079_15	168	102.9
c_079_15	198	103.9
c_079_15	238	108.6
c_079_15	289	112.1
c_079_15	378	119.6
c_079_15	508	126.6
c_079_15	681	132.3
c_079_15	1929	147.0
c_079_15	3486	154.3
c_079_16	1	42.9
c_079_16	3	47.3
c_079_16	7	51.0
c_079_16	14	56.6
c_079_16	28	66.7
c_079_16	49	72.1
c_079_16	70	78.1
c_079_16	98	83.3
c_079_16	126	87.0
c_079_16	168	92.3
c_079_16	198	95.0
c_079_16	238	97.1
c_079_16	289	100.9
c_079_16	378	105.3
c_079_16	508	111.1
c_079_16	681	117.3
c_079_16	1929	132.6
c_079_16	3486	140.6
c_044_01	0.2	47.1
c_044_01	0.5	52.5
c_044_01	0.7	54.4
c_044_01	1	56.3
c_044_01	2	59.8
c_044_01	3	64.8
c_044_01	4	65.2
c_044_01	5	67.6
c_044_01	6	69.5
c_044_01	7	70.5

File No.	Days	Experimental (microstrain/MPa)
c_006_08	1	43.0
c_006_08	3	49.0
c_006_08	7	54.0
c_006_08	14	58.0
c_006_08	28	65.0
c_006_08	55	72.0
c_006_08	85	76.0
c_006_08	180	83.0
c_006_08	269	86.0
c_006_08	375	90.0
c_006_08	569	95.0
c_006_08	767	99.0
c_006_11	1	45.0
c_006_11	3	52.0
c_006_11	7	58.7
c_006_11	14	64.0
c_006_11	28	70.6
c_006_11	55	77.7
c_006_11	85	82.8
c_006_11	180	89.2
c_006_11	269	94.2
c_006_11	375	97.6
c_006_11	569	101.0
c_006_11	767	104.7
c_006_12	1	50.0
c_006_12	3	58.8
c_006_12	7	64.9
c_006_12	14	70.1
c_006_12	28	76.2
c_006_12	55	83.2
c_006_12	85	87.3
c_006_12	180	94.2
c_006_12	269	98.6
c_006_12	375	100.7
c_006_12	569	105.8
c_006_12	767	109.5
c_011_05	1	43.2
c_011_05	3	50.4
c_011_05	7	51.6
c_011_05	14	57.6
c_011_05	28	68.4
c_011_05	56	74.4
c_011_05	90	80.9
c_011_05	120	85.7
c_011_05	150	89.3
c_011_05	181	94.1
c_011_05	270	101.3
c_011_05	492	109.7
c_011_05	514	110.9
c_011_05	689	109.7
c_011_05	965	112.1

File No.	Days	Experimental (microstrain/MPa)
c_044_01	8	71.4
c_044_01	9	73.3
c_044_01	14	77.1
c_044_01	20	80.9
c_044_01	30	85.6
c_044_01	40	88.1
c_044_01	50	90.9
c_044_01	60	91.8
c_044_01	70	94.7
c_044_03	0.2	45.4
c_044_03	0.5	47.2
c_044_03	0.7	47.8
c_044_03	1	49.7
c_044_03	2	56.3
c_044_03	3	57.3
c_044_03	4	59.1
c_044_03	5	62.0
c_044_03	6	62.5
c_044_03	7	63.9
c_044_03	8	64.8
c_044_03	9	66.7
c_044_03	14	69.0
c_044_03	20	71.4
c_044_03	40	78.0
c_044_03	50	81.8
c_044_03	60	83.7
c_044_03	70	86.5
c_044_03	80	89.4
c_044_03	90	91.8
c_044_03	150	95.6
c_044_03	200	99.4
c_044_03	300	103.9
c_044_03	400	108.8
c_044_03	500	109.6
c_044_03	570	111.5
c_046_02	0.2	48.3
c_046_02	0.9	54.2
c_046_02	1	56.7
c_046_02	1.3	57.7
c_046_02	1.9	59.8
c_046_02	2.2	61.4
c_046_02	3.1	63.1
c_046_02	6.3	68.1
c_046_02	7.2	70.3
c_046_02	9.2	71.7
c_046_02	14.3	74.9
c_046_02	15.5	75.8
c_046_02	16.6	77.0
c_046_02	20.9	79.0
c_046_02	24.4	81.6
c_046_02	27.6	82.0

File No.	Days	Experimental (microstrain/MPa)
c_011_05	1103	116.9
c_011_05	1278	116.9
c_011_06	1	46.5
c_011_06	3	50.2
c_011_06	5	53.8
c_011_06	7	54.9
c_011_06	14	60.1
c_011_06	28	65.9
c_011_06	56	73.7
c_011_06	91	80.5
c_011_06	101	82.1
c_011_06	102	82.6
c_011_06	104	83.6
c_011_06	150	89.4
c_011_06	179	93.6
c_011_06	273	99.3
c_011_06	360	100.9
c_011_06	903	108.7
c_011_06	1041	112.9
c_011_06	1111	110.3
c_017_01	1	67.0
c_017_01	7	85.0
c_017_01	14	90.0
c_017_01	21	93.0
c_017_01	28	93.0
c_017_01	43	96.0
c_017_01	56	107.0
c_017_01	70	106.0
c_017_01	90	114.0
c_017_01	117	117.0
c_017_01	150	120.0
c_017_01	178	122.0
c_017_01	211	122.0
c_017_01	243	127.0
c_017_01	348	131.0
c_017_01	422	136.0
c_017_01	540	129.0
c_017_01	790	143.0
c_017_01	1000	144.0
c_017_01	1090	140.0
c_017_01	1250	144.0
c_017_01	1350	144.0
c_017_01	1550	144.0
c_017_01	1750	148.0
c_017_01	2050	160.0
c_017_02	1	42.0
c_017_02	28	71.0
c_017_02	90	85.0
c_017_02	475	104.0
c_017_03	1	45.0
c_017_03	30	53.0

File No.	Days	Experimental (microstrain/MPa)
c_046_02	31	84.0
c_046_02	34.6	85.8
c_046_02	39.2	86.9
c_046_02	46.3	88.7
c_046_02	55.4	91.5
c_046_02	62.4	92.0
c_046_02	71.1	93.5
c_046_04	0.1	45.8
c_046_04	1	50.0
c_046_04	2	55.3
c_046_04	3.1	56.5
c_046_04	4.1	57.4
c_046_04	6.9	61.4
c_046_04	8	62.6
c_046_04	9.8	65.6
c_046_04	11.2	65.7
c_046_04	14.1	67.7
c_046_04	16.9	68.2
c_046_04	18	69.9
c_046_04	21.1	70.2
c_046_04	23.5	71.2
c_046_04	24.9	72.7
c_046_04	32.2	73.6
c_046_04	35	74.6
c_046_04	38.4	76.3
c_046_04	41	77.9
c_046_04	44.5	79.8
c_046_04	48.3	80.4
c_046_04	53	81.5
c_046_04	58.8	82.2
c_046_04	68.5	85.9
c_046_04	81.9	87.4
c_046_04	106.3	90.1
c_046_04	114.1	90.8
c_046_04	137.4	92.7
c_046_04	166.3	96.1
c_046_04	198	97.6
c_046_04	248.8	100.0
c_046_04	280.5	102.4
c_046_04	339.2	104.2
c_046_04	388.6	107.3
c_046_04	498.8	108.5
c_046_04	568.2	110.7
c_055_01	1.9	85.0
c_055_01	5.9	99.8
c_055_01	13	120.1
c_055_01	20.7	139.9
c_055_01	27.3	156.5
c_055_01	41.7	166.0
c_055_01	62.9	176.0
c_055_01	83.6	182.3

File No.	Days	Experimental (microstrain/MPa)
c_017_03	90	68.0
c_017_03	180	83.0
c_017_03	320	90.0
c_017_03	348	87.0
c_017_03	520	104.0
c_017_03	592	98.0
c_017_03	630	105.0
c_017_03	740	105.0
c_017_03	880	108.0
c_017_03	980	108.0
c_017_03	1260	110.0
c_017_03	1540	114.0
c_017_03	1760	114.0
c_017_03	2050	117.0
c_017_05	1	67.0
c_017_05	7	90.0
c_017_05	14	101.0
c_017_05	21	107.0
c_017_05	28	109.0
c_017_05	43	117.0
c_017_05	56	123.0
c_017_05	70	125.0
c_017_05	90	128.0
c_017_05	117	134.0
c_017_05	150	138.0
c_017_05	178	139.0
c_017_05	211	141.0
c_017_05	243	145.0
c_017_05	348	148.0
c_017_05	422	151.0
c_017_05	540	155.0
c_017_05	790	160.0
c_017_05	1000	157.0
c_017_05	1090	157.0
c_017_05	1250	169.0
c_017_05	1350	169.0
c_017_05	1550	172.0
c_017_05	1750	183.0
c_017_05	2050	183.0
c_017_06	1	44.0
c_017_06	3	46.0
c_017_06	4	54.0
c_017_06	7	59.0
c_017_06	23	71.0
c_017_06	28	73.0
c_017_06	90	87.0
c_017_06	95	85.0
c_017_06	183	88.0
c_017_06	331	98.0
c_017_06	475	109.0
c_017_06	517	105.0

File No.	Days	Experimental (microstrain/MPa)
c_055_01	95.7	186.9
c_055_01	111.7	188.0
c_006_01	1	50.0
c_006_01	2	58.0
c_006_01	4	63.0
c_006_01	8	68.0
c_006_01	15	74.0
c_006_01	29	83.0
c_006_01	56	94.0
c_006_01	90	102.0
c_006_01	141	108.0
c_006_01	173	110.0
c_006_01	253	115.0
c_006_01	362	117.0
c_006_01	530	121.0
c_006_01	768	124.0
c_006_02	8	68.0
c_006_02	15	73.0
c_006_02	29	82.0
c_006_02	56	93.0
c_006_02	90	100.0
c_006_02	141	107.0
c_006_02	173	111.0
c_006_02	253	114.0
c_006_02	362	117.0
c_006_02	530	122.0
c_006_02	768	125.0
c_006_03	1	52.0
c_006_03	2	58.0
c_006_03	4	62.0
c_006_03	8	66.0
c_006_03	15	70.0
c_006_03	29	78.0
c_006_03	56	86.0
c_006_03	90	89.0
c_006_03	141	94.0
c_006_03	173	100.0
c_006_03	253	105.0
c_006_03	362	107.0
c_006_03	530	110.0
c_006_03	768	112.0
c_006_04	1	50.0
c_006_04	2	56.0
c_006_04	4	60.0
c_006_04	8	63.0
c_006_04	15	68.0
c_006_04	29	75.0
c_006_04	56	81.0
c_006_04	90	85.0
c_006_04	141	90.0
c_006_04	173	91.0

File No.	Days	Experimental (microstrain/MPa)
c_017_06	549	108.0
c_017_06	713	111.0
c_017_06	920	113.0
c_017_06	1040	114.0
c_017_06	1170	113.0
c_017_06	1320	114.0
c_017_06	1650	118.0
c_017_06	1980	123.0
c_017_07	1	56.0
c_017_07	7	67.0
c_017_07	11	70.0
c_017_07	15	75.0
c_017_07	28	85.0
c_017_07	41	88.0
c_017_07	57	91.0
c_017_07	77	97.0
c_017_07	91	102.0
c_017_07	159	110.0
c_017_07	185	112.0
c_017_07	271	112.0
c_017_07	394	124.0
c_017_07	576	129.0
c_017_08	1	44.0
c_017_08	30	58.0
c_017_08	90	69.0
c_017_08	180	77.0
c_017_08	320	84.0
c_017_08	348	87.0
c_017_08	520	92.0
c_017_08	592	94.0
c_017_08	630	93.0
c_017_08	740	96.0
c_017_08	880	98.0
c_017_08	980	97.0
c_017_08	1285	100.0
c_017_08	1540	103.0
c_017_08	1800	104.0
c_017_08	2050	111.0
c_017_27	1	46.0
c_017_27	3	47.0
c_017_27	14	61.0
c_017_27	21	65.0
c_017_27	28	69.0
c_017_27	43	71.0
c_017_27	57	75.0
c_017_27	71	81.0
c_017_27	94	87.0
c_017_27	154	97.0
c_017_27	203	102.0
c_017_27	479	111.0
c_017_28	1	40.0

File No.	Days	Experimental (microstrain/MPa)
c_006_04	253	93.0
c_006_04	362	96.0
c_006_04	530	103.0
c_006_04	768	107.0
c_006_05	1	58.0
c_006_05	3	70.0
c_006_05	7	77.0
c_006_05	13	83.0
c_006_05	28	91.0
c_006_05	56	101.0
c_006_05	82	106.0
c_006_05	174	113.0
c_006_05	272	115.0
c_006_05	365	120.0
c_006_05	550	123.0
c_006_05	736	127.0
c_006_06	1	73.0
c_006_06	3	84.0
c_006_06	7	94.0
c_006_06	13	101.0
c_006_06	28	112.0
c_006_06	56	123.0
c_006_06	82	129.0
c_006_06	174	137.0
c_006_06	272	141.0
c_006_06	365	145.0
c_006_06	550	149.0
c_006_06	736	154.0
c_006_09	1	90.7
c_006_09	3	107.0
c_006_09	7	119.7
c_006_09	13	130.6
c_006_09	28	144.9
c_006_09	56	160.7
c_006_09	82	169.3
c_006_09	174	182.0
c_006_09	272	187.4
c_006_09	365	190.3
c_006_09	550	194.9
c_006_09	736	198.6
c_006_10	1	94.2
c_006_10	3	105.8
c_006_10	7	125.1
c_006_10	13	142.2
c_006_10	28	161.2
c_006_10	56	176.1
c_006_10	82	187.3
c_006_10	174	204.5
c_006_10	272	213.0
c_011_02	1	64.9
c_011_02	3	73.2

File No.	Days	Experimental (microstrain/MPa)
c_017_28	3	45.0
c_017_28	7	51.0
c_017_28	14	56.0
c_017_28	21	60.0
c_017_28	28	64.0
c_017_28	43	69.0
c_017_28	57	65.0
c_017_28	71	75.0
c_017_28	94	75.0
c_017_28	154	82.0
c_017_28	203	80.0
c_017_28	479	86.0
c_043_01	0.1	34.4
c_043_01	0.2	35.6
c_043_01	0.3	36.2
c_043_01	0.5	36.9
c_043_01	0.7	37.5
c_043_01	1	38.5
c_043_01	2	40.3
c_043_01	3	41.4
c_043_01	5	43.0
c_043_01	7	44.4
c_043_01	10	46.0
c_043_01	14	47.7
c_043_01	21	50.2
c_043_01	28	51.9
c_043_01	42	54.6
c_043_01	56	56.9
c_043_01	70	58.7
c_043_01	91	60.8
c_043_01	119	63.0
c_043_01	175	66.7
c_043_01	273	70.6
c_043_01	360	72.3
c_043_01	542	75.1
c_043_01	724	77.0
c_043_01	1101	79.2
c_043_01	1315	79.8
c_043_02	0.1	32.7
c_043_02	0.2	33.8
c_043_02	0.5	35.0
c_043_02	1	36.5
c_043_02	1.5	37.5
c_043_02	2	38.3
c_043_02	4	40.5
c_043_02	7	42.4
c_043_02	10	43.9
c_043_02	14	45.2
c_043_02	21	47.0
c_043_02	28	48.7
c_043_02	42	50.8

File No.	Days	Experimental (microstrain/MPa)
c_011_02	7	80.6
c_011_02	14	83.4
c_011_02	28	93.6
c_011_02	56	109.4
c_011_02	90	120.5
c_011_02	120	124.2
c_011_02	150	128.8
c_011_02	180	131.6
c_011_02	271	138.1
c_011_02	360	143.6
c_011_02	516	146.4
c_011_02	693	145.5
c_011_02	969	152.0
c_011_02	1105	154.8
c_011_02	1585	153.8
c_011_03	1	66.3
c_011_03	4	75.7
c_011_03	7	81.5
c_011_03	14	89.6
c_011_03	28	101.2
c_011_03	56	110.7
c_011_03	89	118.0
c_011_03	151	129.6
c_011_03	181	133.2
c_011_03	270	139.8
c_011_03	298	140.5
c_011_03	360	143.4
c_011_03	907	152.9
c_011_03	1045	158.0
c_011_03	1137	157.3
c_011_07	1	41.4
c_011_07	3	46.6
c_011_07	7	48.9
c_011_07	14	51.8
c_011_07	28	57.1
c_011_07	56	61.7
c_011_07	90	65.8
c_011_07	121	67.6
c_011_07	150	71.1
c_011_07	181	72.2
c_011_07	270	74.0
c_011_07	360	76.3
c_011_07	540	78.1
c_011_07	727	77.5
c_011_07	941	81.5
c_011_07	1078	82.1
c_011_07	1253	83.9
c_011_08	1	45.0
c_011_08	3	48.6
c_011_08	7	57.0
c_011_08	14	60.5

File No.	Days	Experimental (microstrain/MPa)	File No.	Days	Experimental (microstrain/MPa)
c_043_02	70	54.3	c_011_08	28	64.7
c_043_02	91	55.9	c_011_08	56	71.8
c_043_02	175	60.6	c_011_08	90	76.0
c_043_02	273	63.5	c_011_08	120	79.5
c_043_02	360	64.7	c_011_08	150	80.9
c_043_02	472	66.6	c_011_08	181	84.4
c_043_02	542	67.2	c_011_08	270	88.0
c_043_02	724	69.0	c_011_08	360	89.4
c_043_02	923	70.3	c_011_08	542	94.3
c_043_02	1101	71.3	c_011_08	734	92.2
c_043_02	1315	72.2	c_011_08	948	97.1
c_058_01	1	52.0	c_011_08	1085	98.5
c_058_01	2	56.0	c_011_08	1260	102.0
c_058_01	3	58.0	c_014_01	1	69.7
c_058_01	7	64.0	c_014_01	2	74.9
c_058_01	14	71.0	c_014_01	3	77.0
c_058_01	28	78.0	c_014_01	4	81.1
c_058_01	56	90.0	c_014_01	6	84.4
c_058_01	90	98.0	c_014_01	8	86.3
c_058_01	180	107.0	c_014_01	12	90.5
c_058_01	360	116.0	c_014_01	15	91.5
c_058_01	720	124.0	c_014_01	22	97.8
c_058_02	1	44.0	c_014_01	28	98.8
c_058_02	2	48.0	c_014_01	33	104.0
c_058_02	3	50.0	c_014_01	36	104.0
c_058_02	7	54.0	c_014_01	44	107.1
c_058_02	14	59.0	c_014_01	62	112.3
c_058_02	28	67.0	c_014_01	68	115.5
c_058_02	56	77.0	c_014_01	81	118.6
c_058_02	90	85.0	c_014_01	98	120.7
c_058_02	180	98.0	c_014_01	109	123.8
c_058_02	360	106.0	c_014_01	134	126.9
c_058_02	720	114.0	c_014_01	141	130.0
c_058_02	1080	116.0	c_014_01	155	131.1
c_058_02	1440	118.0	c_014_01	183	133.1
c_058_02	1800	120.0	c_014_01	197	134.2
c_058_03	1	50.0	c_014_01	231	138.3
c_058_03	2	54.0	c_014_01	270	139.4
c_058_03	3	56.0	c_014_01	294	140.4
c_058_03	7	63.0	c_014_01	323	141.5
c_058_03	14	69.0	c_014_01	342	142.5
c_058_03	28	79.0	c_014_01	361	144.6
c_058_03	56	88.0	c_014_02	1	38.5
c_058_03	90	95.0	c_014_02	2	43.7
c_058_03	180	104.0	c_014_02	3	44.7
c_058_03	360	113.0	c_014_02	4	46.8
c_058_03	720	121.0	c_014_02	7	51.0
c_058_03	1080	124.0	c_014_02	9	52.0
c_058_03	1440	127.0	c_014_02	15	57.2
c_058_03	1800	128.0	c_014_02	22	60.3
c_058_04	1	49.0	c_014_02	25	60.3

File No.	Days	Experimental (microstrain/MPa)	File No.	Days	Experimental (microstrain/MPa)
c_058_04	2	54.0	c_014_02	29	62.4
c_058_04	3	58.0	c_014_02	35	63.5
c_058_04	7	65.0	c_014_02	39	65.5
c_058_04	14	72.0	c_014_02	45	64.5
c_058_04	28	81.0	c_014_02	51	68.7
c_058_04	56	94.0	c_014_02	56	70.7
c_058_04	90	103.0	c_014_02	73	74.9
c_058_04	180	116.0	c_014_02	79	75.9
c_058_04	360	126.0	c_014_02	95	77.0
c_058_04	720	135.0	c_014_02	109	81.1
c_058_04	1080	140.0	c_014_02	123	83.2
c_058_04	1440	141.0	c_014_02	141	84.3
c_058_06	1	37.0	c_014_02	144	85.3
c_058_06	2	40.0	c_014_02	157	88.4
c_058_06	3	43.0	c_014_02	165	87.4
c_058_06	7	47.0	c_014_02	184	90.5
c_058_06	14	53.0	c_014_02	217	89.5
c_058_06	28	61.0	c_014_02	270	91.5
c_058_06	56	71.0	c_014_02	289	91.5
c_058_06	90	78.0	c_014_02	309	93.6
c_058_06	180	89.0	c_014_03	1	56.2
c_058_06	360	97.0	c_014_03	2	64.5
c_058_06	720	103.0	c_014_03	3	66.6
c_058_07	1	54.8	c_014_03	7	72.8
c_058_07	2	58.3	c_014_03	10	77.0
c_058_07	3	59.5	c_014_03	14	81.1
c_058_07	7	63.4	c_014_03	17	83.2
c_058_07	14	68.3	c_014_03	20	86.3
c_058_07	28	76.4	c_014_03	27	87.4
c_058_07	56	88.2	c_014_03	31	89.5
c_058_07	90	97.2	c_014_03	36	92.6
c_058_07	180	110.6	c_014_03	43	95.7
c_058_07	360	119.7	c_014_03	58	100.9
c_058_08	1	43.8	c_014_03	66	103.0
c_058_08	2	45.5	c_014_03	73	106.1
c_058_08	3	46.1	c_014_03	80	107.1
c_058_08	7	48.5	c_014_03	101	111.3
c_058_08	14	51.8	c_014_03	120	114.4
c_058_08	28	56.3	c_014_03	129	116.5
c_058_08	56	61.8	c_014_03	163	118.6
c_058_08	90	66.7	c_014_03	177	120.7
c_058_08	180	74.6	c_014_03	255	123.8
c_058_08	360	84.0	c_014_03	275	124.8
c_058_09	1	71.9	c_014_03	308	125.9
c_058_09	2	77.2	c_014_03	348	129.0
c_058_09	3	81.0	c_014_03	391	129.0
c_058_09	7	90.1	c_014_03	455	131.1
c_058_09	14	98.3	c_014_03	534	132.1
c_058_09	28	108.2	c_014_03	572	131.1
c_058_09	56	121.0	c_014_05	0.2	62.4
c_058_09	90	131.9	c_014_05	1	69.7

File No.	Days	Experimental (microstrain/MPa)
c_058_09	180	146.1
c_058_09	360	157.3
c_058_09	720	166.1
c_058_09	1080	170.6
c_058_09	1440	173.8
c_058_09	1800	175.6
c_058_10	1	37.7
c_058_10	2	39.8
c_058_10	3	41.4
c_058_10	7	45.6
c_058_10	14	50.1
c_058_10	28	55.2
c_058_10	56	62.2
c_058_10	90	67.8
c_058_10	180	77.2
c_058_10	360	81.8
c_058_11	1	52.7
c_058_11	2	56.4
c_058_11	3	57.8
c_058_11	7	66.0
c_058_11	14	74.2
c_058_11	28	84.8
c_058_11	56	96.1
c_058_11	90	102.7
c_058_11	180	111.8
c_058_11	360	120.0
c_058_11	720	127.3
c_058_12	1	46.9
c_058_12	2	50.6
c_058_12	3	52.5
c_058_12	7	57.9
c_058_12	14	63.4
c_058_12	28	70.7
c_058_12	56	79.9
c_058_12	90	86.5
c_058_12	180	95.3
c_058_12	360	103.2
c_058_12	360	103.2
c_058_16	1	29.3
c_058_16	2	30.1
c_058_16	3	31.7
c_058_16	7	38.6
c_058_16	14	46.0
c_058_16	28	55.4
c_058_16	56	66.0
c_058_16	90	73.1
c_058_16	180	85.3
c_058_16	360	98.2
c_058_16	720	110.6
c_058_18	1	29.4
c_058_18	2	31.4

File No.	Days	Experimental (microstrain/MPa)
c_014_05	2	72.8
c_014_05	3	75.0
c_014_05	6	80.1
c_014_05	9	84.3
c_014_05	12	86.3
c_014_05	16	87.4
c_014_05	23	93.6
c_014_05	33	97.8
c_014_05	44	101.9
c_014_05	51	103.0
c_014_05	62	106.1
c_014_05	65	107.1
c_014_05	75	111.3
c_014_05	86	113.4
c_014_05	99	114.4
c_014_05	113	117.5
c_014_05	138	118.6
c_014_05	162	120.7
c_014_05	177	121.7
c_014_05	191	122.7
c_014_05	211	123.8
c_014_05	244	126.9
c_014_05	286	132.1
c_014_05	328	131.1
c_014_05	392	133.1
c_014_05	477	135.2
c_014_05	509	136.3
c_014_06	1	39.5
c_014_06	2	44.7
c_014_06	4	48.9
c_014_06	7	52.0
c_014_06	11	53.0
c_014_06	14	56.2
c_014_06	18	58.2
c_014_06	25	62.4
c_014_06	32	62.4
c_014_06	43	66.6
c_014_06	46	66.6
c_014_06	56	69.7
c_014_06	64	69.7
c_014_06	71	71.8
c_014_06	80	73.9
c_014_06	88	72.8
c_014_06	119	76.8
c_014_06	142	78.0
c_014_06	158	78.0
c_014_06	172	80.1
c_014_06	192	81.1
c_014_06	225	82.2
c_014_06	267	86.3
c_014_06	309	86.3

File No.	Days	Experimental (microstrain/MPa)
c_058_18	3	32.4
c_058_18	7	36.5
c_058_18	14	39.9
c_058_18	28	44.4
c_058_18	56	49.0
c_058_18	90	52.6
c_058_18	180	59.7
c_058_18	360	68.1
c_061_02	1	41.7
c_061_02	3	47.4
c_061_02	7	51.2
c_061_02	28	61.2
c_061_02	91	66.8
c_061_02	182	80.2
c_061_02	365	85.9
c_061_02	730	89.7
c_061_02	1095	91.7
c_061_02	1460	92.8
c_061_02	1825	94.8
c_061_02	2190	94.8
c_061_03	1	33.0
c_061_03	3	37.9
c_061_03	7	40.1
c_061_03	28	46.7
c_061_03	91	53.2
c_061_03	182	59.8
c_061_03	365	66.1
c_061_03	730	71.4
c_061_03	1095	72.7
c_061_03	1460	73.9
c_061_03	1825	74.8
c_061_03	2190	77.4
c_061_05	1	41.5
c_061_05	3	48.7
c_061_05	7	52.5
c_061_05	28	66.4
c_061_05	91	84.7
c_061_05	182	98.8
c_061_05	365	107.5
c_061_05	730	114.3
c_061_05	1095	118.4
c_061_05	1460	120.5
c_061_05	1825	123.3
c_061_05	2190	123.9
c_061_06	1	36.4
c_061_06	3	40.3
c_061_06	7	43.5
c_061_06	28	54.4
c_061_06	91	65.6
c_061_06	182	74.8
c_061_06	365	85.1

File No.	Days	Experimental (microstrain/MPa)
c_014_06	373	88.4
c_014_06	458	88.4
c_014_06	595	89.5
c_063_24	0.2	47.8
c_063_24	1.2	49.2
c_063_24	2	50.3
c_063_24	3	50.5
c_063_24	4.1	50.9
c_063_24	5	52.0
c_063_24	6	52.5
c_063_24	7	53.3
c_063_24	14	54.2
c_063_24	21	54.0
c_063_24	28	55.4
c_063_24	56	56.2
c_063_24	90	58.4
c_063_24	122	59.5
c_063_24	147	60.6
c_063_24	182	61.9
c_063_24	273	64.8
c_063_24	364	65.2
c_063_24	454	67.1
c_063_24	546	68.5
c_063_24	636	70.1
c_063_24	731	70.9
c_063_25	1	51.8
c_063_25	3	57.4
c_063_25	6	62.1
c_063_25	9	64.9
c_063_25	12	67.5
c_063_25	15	70.1
c_063_25	23	75.0
c_063_25	30	78.2
c_063_25	40	81.4
c_063_25	50	84.5
c_063_25	60	86.7
c_063_25	70	88.7
c_063_25	80	90.1
c_063_25	90	91.4
c_063_25	100	92.9
c_063_25	120	94.9
c_063_25	140	96.5
c_063_25	180	99.9
c_063_25	220	103.0
c_063_25	260	104.5
c_063_25	300	106.1
c_063_25	351	109.1
c_063_25	393	110.1
c_063_25	456	110.9
c_063_25	512	112.5
c_063_25	568	115.8

File No.	Days	Experimental (microstrain/MPa)	File No.	Days	Experimental (microstrain/MPa)
c_061_06	730	89.6	c_063_25	666	116.5
c_061_06	1095	91.7	c_063_25	701	117.9
c_061_06	1460	93.3	c_063_25	731	118.6
c_061_06	1825	92.1	c_063_27	1	50.3
c_061_06	2190	93.6	c_063_27	3	54.7
c_063_02	1	65.6	c_063_27	6	58.6
c_063_02	2	72.2	c_063_27	9	61.6
c_063_02	3	76.8	c_063_27	12	63.9
c_063_02	4	79.2	c_063_27	15	65.9
c_063_02	7	84.8	c_063_27	18	67.4
c_063_02	10	89.1	c_063_27	23	69.9
c_063_02	14	92.3	c_063_27	30	72.2
c_063_02	17	94.8	c_063_27	35	73.8
c_063_02	21	97.0	c_063_27	40	74.9
c_063_02	28	97.2	c_063_27	50	77.2
c_063_02	35	98.2	c_063_27	60	79.3
c_063_02	42	103.4	c_063_27	70	80.9
c_063_02	56	105.6	c_063_27	80	81.9
c_063_02	71	108.3	c_063_27	90	83.1
c_063_02	84	112.9	c_063_27	120	85.0
c_063_02	98	114.8	c_063_27	160	87.6
c_063_02	105	116.1	c_063_27	200	90.0
c_063_02	165	126.1	c_063_27	240	91.7
c_063_02	182	126.5	c_063_27	280	93.0
c_063_02	196	127.8	c_063_27	320	94.1
c_063_02	210	129.4	c_063_27	360	95.1
c_063_02	245	132.6	c_063_27	419	96.1
c_063_02	301	136.3	c_063_27	490	98.0
c_063_02	329	138.8	c_063_27	608	100.8
c_063_02	364	140.7	c_063_27	671	101.9
c_063_02	457	143.4	c_063_27	706	102.4
c_063_02	488	146.1	c_063_27	736	103.2
c_063_02	518	148.7	c_063_28	1	50.2
c_063_02	549	150.1	c_063_28	3	54.8
c_063_03	1	60.2	c_063_28	6	59.2
c_063_03	3	66.6	c_063_28	9	62.0
c_063_03	6	71.2	c_063_28	12	64.5
c_063_03	9	74.7	c_063_28	15	66.6
c_063_03	12	77.9	c_063_28	18	68.2
c_063_03	15	80.0	c_063_28	23	70.4
c_063_03	18	83.6	c_063_28	30	73.0
c_063_03	23	85.8	c_063_28	40	76.1
c_063_03	30	89.6	c_063_28	50	78.6
c_063_03	40	93.1	c_063_28	60	80.7
c_063_03	50	96.0	c_063_28	70	82.3
c_063_03	70	100.4	c_063_28	80	83.9
c_063_03	90	103.8	c_063_28	100	86.5
c_063_03	100	105.0	c_063_28	120	88.5
c_063_03	120	107.6	c_063_28	160	91.7
c_063_03	140	109.7	c_063_28	200	94.0
c_063_03	180	113.0	c_063_28	240	96.0

File No.	Days	Experimental (microstrain/MPa)
c_063_03	220	115.3
c_063_03	260	117.9
c_063_03	300	119.6
c_063_03	362	122.6
c_063_03	425	126.5
c_063_03	453	127.6
c_063_03	516	129.5
c_063_03	572	131.5
c_063_03	642	132.6
c_063_03	735	135.2
c_063_03	766	136.0
c_063_03	796	136.7
c_063_06	1	60.7
c_063_06	12	80.4
c_063_06	13	82.0
c_063_06	19	85.4
c_063_06	26	88.9
c_063_06	34	92.6
c_063_06	40	94.4
c_063_06	61	99.0
c_063_06	77	103.4
c_063_06	89	106.0
c_063_06	117	111.1
c_063_06	139	113.4
c_063_06	166	116.2
c_063_06	181	117.8
c_063_06	201	119.6
c_063_06	215	121.5
c_063_06	257	124.5
c_063_06	292	127.1
c_063_06	313	128.8
c_063_06	362	131.8
c_063_06	390	135.1
c_063_06	418	137.1
c_063_06	488	140.4
c_063_06	544	143.1
c_063_06	579	144.5
c_063_06	642	146.2
c_063_06	700	147.6
c_063_06	731	149.3
c_063_06	761	150.9
c_063_15	1	100.8
c_063_15	2	111.4
c_063_15	3	109.4
c_063_15	4	111.0
c_063_15	6	113.2
c_063_15	10	116.8
c_063_15	12	119.9
c_063_15	14	123.6
c_063_15	18	124.2
c_063_15	26	125.9

File No.	Days	Experimental (microstrain/MPa)
c_063_28	280	97.1
c_063_28	320	101.1
c_063_28	364	102.9
c_063_28	420	105.2
c_063_28	483	107.5
c_063_28	546	109.5
c_063_28	609	110.4
c_063_28	672	111.1
c_063_28	702	111.9
c_063_28	733	113.0
c_063_30	0.2	33.5
c_063_30	1.2	34.6
c_063_30	2	35.3
c_063_30	3	35.6
c_063_30	4.1	36.0
c_063_30	5	36.4
c_063_30	6	36.7
c_063_30	7	36.8
c_063_30	14	37.6
c_063_30	21	37.3
c_063_30	28	38.1
c_063_30	56	38.8
c_063_30	90	40.6
c_063_30	122	41.3
c_063_30	147	42.9
c_063_30	182	42.2
c_063_30	273	44.2
c_063_30	364	44.0
c_063_30	454	44.8
c_063_30	546	45.6
c_063_30	636	46.0
c_063_30	731	46.3
c_063_31	0.2	33.8
c_063_31	1.4	35.0
c_063_31	2.1	35.3
c_063_31	3.1	35.4
c_063_31	4.2	36.1
c_063_31	5.1	36.2
c_063_31	6.1	36.4
c_063_31	7.1	37.0
c_063_31	14	37.2
c_063_31	21	37.6
c_063_31	28	38.1
c_063_31	56	39.2
c_063_31	90	40.9
c_063_31	122	41.5
c_063_31	147	41.9
c_063_31	182	41.7
c_063_31	273	44.0
c_063_31	364	44.2
c_063_31	454	45.0

File No.	Days	Experimental (microstrain/MPa)
c_063_15	32	131.4
c_063_15	39	132.9
c_063_15	46	135.1
c_063_15	53	135.7
c_063_15	66	141.8
c_063_15	75	142.5
c_063_15	90	144.6
c_063_15	105	147.9
c_063_15	140	156.1
c_063_15	175	161.8
c_063_15	204	169.6
c_063_15	251	173.7
c_063_15	299	180.2
c_063_15	348	185.9
c_063_15	398	187.4
c_063_15	495	194.8
c_063_15	588	198.7
c_063_15	706	199.4
c_063_15	761	200.4
c_063_16	1	62.9
c_063_16	2	66.9
c_063_16	3	69.7
c_063_16	5	73.8
c_063_16	7	77.0
c_063_16	18	88.0
c_063_16	23	92.7
c_063_16	30	96.6
c_063_16	40	100.7
c_063_16	48	102.7
c_063_16	63	111.9
c_063_16	110	125.6
c_063_16	124	130.3
c_063_16	153	136.4
c_063_16	185	141.0
c_063_16	216	145.7
c_063_16	277	151.9
c_063_16	306	155.0
c_063_16	368	157.4
c_063_16	424	162.2
c_063_16	491	165.2
c_063_16	524	166.5
c_063_16	559	168.1
c_063_16	604	168.6
c_063_16	667	170.7
c_063_16	699	172.1
c_063_16	786	174.2
c_063_16	817	174.2
c_063_16	849	174.5
c_063_17	1	57.3
c_063_17	2	60.8
c_063_17	3	63.5

File No.	Days	Experimental (microstrain/MPa)
c_063_31	546	45.5
c_063_31	636	46.1
c_063_31	731	46.3
c_069_05	0.1	53.1
c_069_05	0.4	57.2
c_069_05	0.8	59.8
c_069_05	1.8	67.0
c_069_05	6.9	73.9
c_069_05	12.9	90.1
c_069_05	45.5	89.4
c_069_05	144	117.1
c_069_06	0.2	58.2
c_069_06	0.7	65.0
c_069_06	1.6	70.0
c_069_06	6.5	82.2
c_069_06	13	90.9
c_069_06	65.3	117.7
c_069_06	144	126.9
c_088_15	1	26.9
c_088_15	7	42.5
c_088_15	19	47.9
c_088_15	40	52.2
c_088_15	44	52.4
c_088_15	47	52.7
c_088_15	82	56.5
c_088_15	99	57.3
c_088_15	173	59.8
c_088_15	209	59.8
c_088_15	236	61.8
c_037_02	0.1	27.3
c_037_02	0.3	28.1
c_037_02	0.5	28.6
c_037_02	1	29.1
c_037_02	2	29.7
c_037_02	3	30.2
c_037_02	4	30.0
c_037_02	5	30.0
c_037_02	6	30.2
c_037_02	8	30.5
c_037_02	15	32.4
c_037_02	21	33.3
c_037_02	28	33.2
c_037_02	56	33.7
c_037_02	84	34.8
c_037_02	112	35.1
c_037_02	140	34.3
c_037_02	168	34.3
c_037_02	196	34.3
c_037_04	0.1	27.5
c_037_04	0.3	27.9
c_037_04	0.5	28.5

File No.	Days	Experimental (microstrain/MPa)
c_063_17	7	69.5
c_063_17	8	70.8
c_063_17	10	73.6
c_063_17	13	76.9
c_063_17	16	79.4
c_063_17	20	82.6
c_063_17	27	87.2
c_063_17	35	90.9
c_063_17	42	94.3
c_063_17	48	96.6
c_063_17	55	99.4
c_063_17	67	102.8
c_063_17	83	105.6
c_063_17	97	108.9
c_063_17	125	113.5
c_063_17	168	120.9
c_063_17	202	126.2
c_063_17	259	134.5
c_063_17	306	139.9
c_063_17	363	146.0
c_063_17	425	148.7
c_063_17	544	154.6
c_063_17	642	158.5
c_063_17	698	159.5
c_063_17	762	159.4
c_063_17	817	160.1
c_063_18	0.2	37.1
c_063_18	1.2	38.2
c_063_18	2	38.8
c_063_18	3	39.3
c_063_18	4.1	39.7
c_063_18	5	40.6
c_063_18	6	40.9
c_063_18	7	40.9
c_063_18	14	41.5
c_063_18	21	41.7
c_063_18	28	42.5
c_063_18	56	43.3
c_063_18	90	45.0
c_063_18	122	46.2
c_063_18	146	47.3
c_063_18	182	47.8
c_063_18	273	49.7
c_063_18	364	49.3
c_063_18	454	50.8
c_063_18	546	51.5
c_063_18	636	52.4
c_063_18	731	52.6
c_072_06	12.5	33.4
c_072_06	25	38.3
c_072_06	37.5	41.1

File No.	Days	Experimental (microstrain/MPa)
c_037_04	1	29.2
c_037_04	2	30.2
c_037_04	3	33.0
c_037_04	4	33.4
c_037_04	5	33.9
c_037_04	6	33.4
c_037_04	7	33.2
c_037_04	14	35.2
c_037_04	21	35.5
c_037_04	28	36.9
c_037_04	56	41.6
c_037_04	84	43.1
c_037_04	112	44.9
c_037_04	140	45.9
c_037_04	168	46.4
c_037_04	196	46.7
c_037_04	224	46.9
c_037_04	252	47.5
c_037_04	280	48.3
c_037_04	308	48.7
c_037_04	336	49.0
c_037_04	364	49.3
c_051_02	1	22.2
c_051_02	4.8	23.4
c_051_02	5.8	23.9
c_051_02	7	24.2
c_051_02	8	24.2
c_051_02	9	23.9
c_051_02	12	24.2
c_051_02	14.2	24.2
c_051_02	15.9	24.2
c_051_02	19	24.4
c_051_02	21	24.7
c_051_02	21.9	24.7
c_051_02	26	25.1
c_051_02	30.9	24.4
c_051_02	37	25.1
c_051_02	43.9	25.4
c_051_02	57.8	25.9
c_051_02	84	26.1
c_051_02	92	26.1
c_051_02	105.9	26.1
c_051_02	168.9	26.3
c_051_02	196.9	27.3
c_051_02	224.9	28.3
c_051_02	253.9	28.3
c_051_02	284.8	27.8
c_051_02	314.1	27.8
c_051_02	347.9	29.5
c_051_02	363.1	28.8
c_051_02	366	28.5

File No.	Days	Experimental (microstrain/MPa)
c_072_06	50	43.0
c_072_06	62.5	45.0
c_072_06	75	46.1
c_072_06	87.5	46.9
c_072_06	100	48.0
c_072_06	112.5	48.9
c_072_06	125	49.8
c_072_06	137.5	50.2
c_072_06	150	50.6
c_072_06	162.5	51.1
c_072_06	175	51.8
c_072_06	187.5	52.1
c_072_06	200	52.6
c_072_06	212.5	52.8
c_072_06	225	53.1
c_072_06	237.5	53.4
c_072_06	250	53.4
c_072_06	262.5	53.7
c_072_06	275	53.9
c_072_06	287.5	54.3
c_072_06	300	54.3
c_072_06	312.5	54.7
c_072_06	325	54.7
c_072_06	337.5	55.1
c_072_06	350	55.1
c_072_08	12.5	44.1
c_072_08	25	47.6
c_072_08	37.5	50.6
c_072_08	50	52.5
c_072_08	62.5	54.4
c_072_08	75	55.9
c_072_08	87.5	56.7
c_072_08	100	57.6
c_072_08	112.5	58.3
c_072_08	125	58.9
c_072_08	137.5	59.4
c_072_08	150	59.6
c_072_08	162.5	59.9
c_072_08	175	60.4
c_072_08	187.5	60.5
c_072_08	200	60.8
c_072_08	212.5	61.1
c_072_08	225	61.5
c_072_08	237.5	61.7
c_072_08	250	62.1
c_072_08	262.5	62.2
c_072_08	275	62.4
c_072_08	287.5	62.8
c_072_08	300	63.2
c_072_08	312.5	63.2
c_072_08	325	64.0

File No.	Days	Experimental (microstrain/MPa)
c_051_04	1	24.5
c_051_04	4.9	25.4
c_051_04	5.8	25.8
c_051_04	7	25.8
c_051_04	8	25.9
c_051_04	9	25.9
c_051_04	12	26.3
c_051_04	14.2	26.5
c_051_04	15.9	26.7
c_051_04	19.1	26.9
c_051_04	21.1	27.3
c_051_04	26	27.1
c_051_04	30.9	27.4
c_051_04	37	27.7
c_051_04	44	28.4
c_051_04	57.9	28.7
c_051_04	81.1	29.5
c_051_04	93	29.5
c_051_04	107	29.5
c_051_04	121.1	29.7
c_051_04	170.1	30.3
c_051_04	198.1	30.8
c_051_04	226.1	30.9
c_051_04	255.1	31.0
c_051_04	284.8	31.2
c_051_04	314	31.5
c_051_04	347.8	32.2
c_051_04	363	32.1
c_051_04	366	32.1
c_051_10	1	29.2
c_051_10	1.9	29.7
c_051_10	2.8	30.7
c_051_10	5.9	31.4
c_051_10	7.8	31.9
c_051_10	7.9	31.4
c_051_10	8.7	32.4
c_051_10	12.8	33.1
c_051_10	15.8	33.1
c_051_10	20.5	34.1
c_051_10	30.8	34.1
c_051_10	41.6	35.5
c_051_10	70.9	37.5
c_051_10	78.8	37.2
c_051_10	92.8	38.2
c_051_10	110.5	39.2
c_051_10	155.8	40.8
c_051_10	187.8	41.8
c_051_10	211.7	43.3
c_051_10	240.7	44.0
c_051_10	271.7	44.2
c_051_10	301.5	44.5

File No.	Days	Experimental (microstrain/MPa)
c_072_08	337.5	64.2
c_072_08	350	64.4
c_072_09	12.5	44.1
c_072_09	25	50.0
c_072_09	37.5	52.9
c_072_09	50	54.8
c_072_09	62.5	56.6
c_072_09	75	57.8
c_072_09	87.5	58.7
c_072_09	100	59.6
c_072_09	112.5	60.6
c_072_09	125	61.5
c_072_09	137.5	62.4
c_072_09	150	62.7
c_072_09	162.5	63.0
c_072_09	175	63.7
c_072_09	187.5	63.9
c_072_09	200	64.2
c_072_09	212.5	64.3
c_072_09	225	64.7
c_072_09	237.5	64.9
c_072_09	250	65.2
c_072_09	262.5	65.3
c_072_09	275	69.8
c_072_09	287.5	66.1
c_072_09	300	66.4
c_072_09	312.5	66.5
c_072_09	325	66.8
c_072_09	337.5	67.3
c_072_09	350	67.4
c_072_10	12.5	48.0
c_072_10	25	53.0
c_072_10	37.5	56.1
c_072_10	50	58.2
c_072_10	62.5	60.2
c_072_10	75	61.6
c_072_10	87.5	62.7
c_072_10	100	63.9
c_072_10	112.5	64.9
c_072_10	125	65.8
c_072_10	137.5	66.3
c_072_10	150	66.9
c_072_10	162.5	67.3
c_072_10	175	67.8
c_072_10	187.5	68.1
c_072_10	200	68.4
c_072_10	212.5	68.6
c_072_10	225	69.0
c_072_10	237.5	69.3
c_072_10	250	69.5
c_072_10	262.5	69.7

File No.	Days	Experimental (microstrain/MPa)
c_051_10	334.5	46.6
c_051_10	365	47.1
c_051_12	0.9	27.8
c_051_12	2.3	30.2
c_051_12	3.2	31.3
c_051_12	6.3	32.5
c_051_12	13.2	34.7
c_051_12	16.2	34.6
c_051_12	20.9	35.0
c_051_12	31.2	36.7
c_051_12	41.6	37.7
c_051_12	70.8	39.6
c_051_12	78.8	39.5
c_051_12	92.7	40.1
c_051_12	110.5	40.8
c_051_12	155.8	42.2
c_051_12	187.8	43.0
c_051_12	211.7	43.3
c_051_12	240.7	43.7
c_051_12	271.7	44.2
c_051_12	301.5	44.5
c_051_12	334.5	45.6
c_051_12	365	45.7
c_051_16	1	52.1
c_051_16	1.9	52.2
c_051_16	5.8	54.3
c_051_16	8	51.6
c_051_16	9	51.8
c_051_16	13.6	52.2
c_066_02	0.2	26.3
c_066_02	4	31.5
c_066_02	14.5	34.3
c_066_02	26	36.4
c_066_02	50	39.2
c_066_02	74.8	42.4
c_066_02	99.8	44.2
c_066_02	122.9	45.9
c_066_02	150.7	47.4
c_066_02	171.9	48.9
c_066_02	199.8	49.8
c_066_02	212.6	50.3
c_066_04	1.1	25.6
c_066_04	2.8	31.5
c_066_04	9.5	36.7
c_066_04	22.6	42.6
c_066_04	51.4	50.8
c_066_04	77.9	56.3
c_066_04	103.3	60.6
c_066_04	125.8	63.9
c_066_04	148.9	66.9
c_066_04	175.3	69.1

File No.	Days	Experimental (microstrain/MPa)
c_072_10	275	69.9
c_072_10	287.5	70.2
c_072_10	300	70.5
c_072_10	312.5	70.7
c_072_10	325	71.0
c_072_10	337.5	71.4
c_072_10	350	71.4
c_073_01	0.2	48.8
c_073_01	0.6	57.5
c_073_01	1.1	59.4
c_073_01	2	62.5
c_073_01	5.6	75.3
c_073_01	6.6	79.6
c_073_01	8.7	82.4
c_073_01	12.9	86.9
c_073_01	15.6	95.4
c_073_01	19.2	101.4
c_073_01	27.9	107.4
c_073_01	37.1	112.3
c_073_01	51.2	118.8
c_073_01	65.4	131.1
c_073_01	100	136.5
c_073_01	128	141.7
c_073_01	153	146.9
c_073_01	206	152.2
c_073_02	0.3	51.7
c_073_02	0.6	59.6
c_073_02	1.1	67.4
c_073_02	2.2	72.6
c_073_02	5.4	83.3
c_073_02	6.3	85.9
c_073_02	8.4	93.9
c_073_02	11.6	97.8
c_073_02	15.2	108.5
c_073_02	20.9	115.0
c_073_02	27.6	123.3
c_073_02	34.5	132.7
c_073_02	47.5	140.3
c_073_02	65.4	150.4
c_073_02	96.3	160.6
c_073_02	120	170.8
c_073_02	152	175.8
c_073_02	202	182.6
c_073_02	240	188.7
c_073_02	315	191.5
c_073_02	371	195.1
c_073_02	464	197.3
c_073_02	767	204.0
c_073_02	963	210.5
c_078_02	3	41.3
c_078_02	4	41.7

File No.	Days	Experimental (microstrain/MPa)
c_066_04	199.2	71.0
c_066_04	224.7	71.9
c_066_04	250.3	72.9
c_066_04	269.2	73.6
c_015_02	1	66.0
c_015_02	7	82.0
c_015_02	28	96.0
c_015_02	91	108.0
c_015_02	175	113.0
c_015_02	365	117.0
c_015_02	897	120.0
c_015_03	1	67.0
c_015_03	7	86.0
c_015_03	28	104.0
c_015_03	91	120.0
c_015_03	175	128.0
c_015_03	365	136.0
c_015_03	897	141.0
c_015_06	1	63.0
c_015_06	7	79.0
c_015_06	28	93.0
c_015_06	91	105.0
c_015_06	175	112.0
c_015_06	365	118.0
c_015_06	897	121.0
c_015_07	1	63.0
c_015_07	7	81.0
c_015_07	28	100.0
c_015_07	91	118.0
c_015_07	175	126.0
c_015_07	365	137.0
c_015_07	897	138.0
c_030_01	0.1	32.0
c_030_01	2.7	40.6
c_030_01	4.8	43.0
c_030_01	11.1	49.1
c_030_01	19.1	55.9
c_030_01	33.5	60.0
c_030_01	103	66.9
c_030_01	236	79.8
c_030_01	403	83.6
c_058_13	1	39.8
c_058_13	2	41.9
c_058_13	3	43.4
c_058_13	7	47.4
c_058_13	14	50.6
c_058_13	28	54.6
c_058_13	56	60.0
c_058_13	90	63.6
c_058_13	180	70.3
c_058_13	360	78.4

File No.	Days	Experimental (microstrain/MPa)
c_078_02	8	47.5
c_078_02	14	52.5
c_078_02	21	56.2
c_078_02	28	59.0
c_078_02	36	63.1
c_078_02	43	65.8
c_078_02	52	67.7
c_078_02	74	72.2
c_078_02	94	78.1
c_078_02	114	81.9
c_078_02	136	84.5
c_078_02	162	86.4
c_078_02	184	88.6
c_078_02	197	89.5
c_078_02	224	90.3
c_078_02	317	93.1
c_078_02	417	97.0
c_078_02	522	98.2
c_078_02	722	100.9
c_078_02	899	101.4
c_078_02	1101	103.4
c_078_02	1310	105.1
c_078_02	1452	105.7
c_078_02	3802	113.0
c_078_02	4300	118.9
c_078_02	5148	116.3
c_078_02	6321	112.0
c_078_06	1	33.8
c_078_06	2	37.6
c_078_06	3	39.5
c_078_06	7	44.1
c_078_06	14	49.1
c_078_06	21	52.0
c_078_06	28	54.0
c_078_06	41	57.8
c_078_06	55	60.7
c_078_06	107	69.4
c_078_06	143	73.0
c_078_06	169	75.0
c_078_06	308	82.0
c_078_06	356	84.0
c_078_06	420	86.1
c_078_06	457	85.6
c_078_06	500	86.9
c_078_06	542	85.8
c_078_06	632	88.4
c_078_06	646	89.1
c_078_06	673	88.8
c_078_06	764	89.4
c_078_06	969	92.0
c_078_06	1169	92.7

File No.	Days	Experimental (microstrain/MPa)
c_061_09	1	27.2
c_061_09	3	31.0
c_061_09	7	35.9
c_061_09	28	45.3
c_061_09	91	55.6
c_061_09	182	61.6
c_061_09	365	65.9
c_061_09	730	69.4
c_061_09	1095	71.4
c_061_09	1460	72.7
c_061_09	1825	74.1
c_061_09	2190	73.8
c_061_11	1	45.4
c_061_11	3	52.1
c_061_11	7	59.0
c_061_11	28	72.7
c_061_11	91	84.9
c_061_11	182	93.7
c_061_11	365	100.5
c_061_11	730	105.1
c_061_11	1095	107.8
c_061_11	1460	109.6
c_061_11	1825	109.3
c_061_11	2190	112.6
c_061_12	1	39.5
c_061_12	3	43.6
c_061_12	7	49.6
c_061_12	28	60.0
c_061_12	91	71.1
c_061_12	182	78.2
c_061_12	365	84.7
c_061_12	730	89.8
c_061_12	1095	92.4
c_061_12	1460	94.1
c_061_12	1825	96.5
c_061_12	2190	96.4
c_061_15	1	26.6
c_061_15	3	32.0
c_061_15	7	34.7
c_061_15	28	41.4
c_061_15	91	48.1
c_061_15	182	52.1
c_061_15	365	51.7
c_061_15	730	54.6
c_061_15	1095	56.3
c_061_15	1460	57.3
c_061_15	1825	58.7
c_061_15	2190	58.4
c_063_11	1	52.8
c_063_11	2	55.7
c_063_11	4	58.4

File No.	Days	Experimental (microstrain/MPa)
c_078_06	1548	95.4
c_078_06	1757	97.0
c_078_06	1899	95.8
c_078_06	4249	101.6
c_078_06	4747	104.5
c_078_06	5595	104.4
c_078_06	6768	101.9
c_088_02	1	20.5
c_088_02	2	34.7
c_088_02	8	37.9
c_088_02	9	38.4
c_088_02	12	40.5
c_088_02	15	42.3
c_088_02	20	43.5
c_088_02	22	45.1
c_088_02	26	44.5
c_088_02	30	44.8
c_088_02	33	46.6
c_088_02	35	45.8
c_088_02	54	49.0
c_088_02	70	50.0
c_088_02	82	52.5
c_088_02	105	53.8
c_088_02	110	54.2
c_088_02	145	55.2
c_088_02	162	55.3
c_088_02	236	57.9
c_088_05	1	32.5
c_088_05	2	37.2
c_088_05	6	40.0
c_088_05	12	44.9
c_088_05	16	47.1
c_088_05	19	46.2
c_088_05	21	46.9
c_088_05	40	52.1
c_088_05	56	54.0
c_088_05	68	55.6
c_088_05	91	58.2
c_088_05	96	57.8
c_088_05	131	60.4
c_088_05	148	61.0
c_088_05	222	62.8
c_088_05	236	64.4
c_088_13	1	39.6
c_088_13	2	41.6
c_088_13	11	54.1
c_088_13	14	56.0
c_088_13	35	64.5
c_088_13	42	66.6
c_088_13	60	70.1
c_088_13	77	73.2

File No.	Days	Experimental (microstrain/MPa)
c_063_11	5	60.0
c_063_11	8	64.3
c_063_11	11	67.5
c_063_11	15	71.0
c_063_11	19	72.7
c_063_11	27	75.9
c_063_11	33	77.7
c_063_11	47	81.4
c_063_11	61	84.4
c_063_11	76	87.0
c_063_11	97	90.0
c_063_11	125	94.0
c_063_11	146	96.7
c_063_11	174	99.9
c_063_11	197	102.5
c_063_11	231	105.9
c_063_11	244	105.5
c_063_11	285	107.5
c_063_11	369	110.4
c_063_11	425	110.4
c_063_11	488	111.1
c_063_11	551	112.1
c_063_11	587	112.5
c_063_11	641	112.7
c_063_11	705	113.0
c_063_11	760	113.2
c_063_12	1	47.8
c_063_12	2	51.2
c_063_12	5	56.9
c_063_12	7	58.5
c_063_12	12	62.1
c_063_12	16	64.6
c_063_12	19	65.6
c_063_12	27	69.2
c_063_12	34	71.5
c_063_12	49	75.8
c_063_12	62	78.2
c_063_12	77	81.1
c_063_12	91	83.8
c_063_12	112	87.0
c_063_12	133	89.2
c_063_12	155	92.9
c_063_12	184	96.0
c_063_12	196	97.5
c_063_12	216	99.4
c_063_12	223	99.3
c_063_12	284	102.6
c_063_12	363	104.6
c_063_12	393	106.1
c_063_12	492	107.2
c_063_12	545	108.2

File No.	Days	Experimental (microstrain/MPa)
c_088_13	94	75.7
c_088_13	168	81.8
c_088_13	204	84.0
c_088_13	231	84.8
c_088_35	1	28.3
c_088_35	2	31.7
c_088_35	8	35.2
c_088_35	15	38.7
c_088_35	22	40.3
c_088_35	38	42.1
c_088_35	77	48.7
c_088_35	94	49.5
c_088_35	155	51.7
c_088_35	224	52.6
c_088_35	226	53.0
c_079_01	1	50.1
c_079_01	3	61.0
c_079_01	6	64.6
c_079_01	7	68.1
c_079_01	9	71.1
c_079_01	13	77.7
c_079_01	20	86.3
c_079_01	34	98.0
c_079_01	55	111.4
c_079_01	76	118.7
c_079_01	104	129.9
c_079_01	132	138.6
c_079_01	174	147.3
c_079_01	204	151.4
c_079_01	244	154.9
c_079_01	295	160.7
c_079_01	384	167.4
c_079_01	514	173.1
c_079_01	687	178.9
c_079_01	1935	189.1
c_079_01	3492	190.7
c_079_02	1	48.0
c_079_02	3	53.3
c_079_02	7	61.3
c_079_02	14	70.3
c_079_02	28	83.7
c_079_02	49	98.7
c_079_02	70	107.4
c_079_02	98	118.9
c_079_02	126	126.9
c_079_02	168	135.9
c_079_02	198	140.0
c_079_02	238	144.1
c_079_02	289	149.1
c_079_02	378	156.7
c_079_02	508	162.7

File No.	Days	Experimental (microstrain/MPa)
c_063_12	580	108.4
c_063_12	636	108.7
c_063_12	700	108.9
c_063_12	762	108.9
c_089_01	2	28.0
c_089_01	7	30.3
c_089_01	12	31.5
c_089_01	17	32.5
c_089_01	22	33.3
c_089_01	32	34.5
c_089_01	42	35.4
c_089_01	52	36.2
c_089_01	62	37.0
c_089_01	72	37.4
c_089_01	122	39.7
c_089_01	172	41.0
c_089_01	222	41.9
c_089_01	272	42.6
c_089_01	322	43.1
c_089_01	372	43.7
c_089_01	422	44.1
c_089_01	472	44.5
c_089_01	572	45.3
c_089_01	672	45.7
c_089_01	772	46.0
c_089_01	872	46.7
c_089_01	972	47.0
c_089_01	1472	48.0
c_089_02	2	29.8
c_089_02	7	33.2
c_089_02	12	34.5
c_089_02	17	35.6
c_089_02	22	36.7
c_089_02	32	37.8
c_089_02	42	38.8
c_089_02	52	39.7
c_089_02	62	40.4
c_089_02	72	41.1
c_089_02	122	43.2
c_089_02	172	44.7
c_089_02	222	45.8
c_089_02	272	46.8
c_089_02	322	47.3
c_089_02	372	47.9
c_089_02	422	48.3
c_089_02	472	48.7
c_089_02	572	49.3
c_089_02	672	49.8
c_089_02	772	50.3
c_089_02	872	50.7
c_089_02	972	51.1

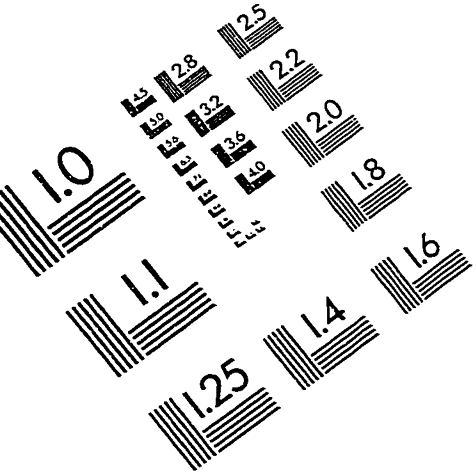
File No.	Days	Experimental (microstrain/MPa)
c_079_02	681	168.1
c_079_02	1929	179.3
c_079_02	3486	183.0
c_079_03	1	47.6
c_079_03	3	55.6
c_079_03	7	61.4
c_079_03	21	73.6
c_079_03	42	91.6
c_079_03	63	100.4
c_079_03	91	113.4
c_079_03	119	119.6
c_079_03	161	129.4
c_079_03	191	135.1
c_079_03	231	138.4
c_079_03	282	143.7
c_079_03	371	151.4
c_079_03	501	157.1
c_079_03	674	163.0
c_079_03	1922	175.4
c_079_04	1	47.1
c_079_04	9	57.7
c_079_04	14	63.1
c_079_04	28	75.4
c_079_04	35	79.7
c_079_04	56	89.6
c_079_04	84	102.9
c_079_04	112	108.7
c_079_04	154	118.6
c_079_04	184	123.3
c_079_04	224	126.4
c_079_04	275	131.9
c_079_04	364	139.1
c_079_04	494	145.0
c_079_04	667	150.6
c_079_04	1915	163.0
c_079_04	3472	166.3
c_079_05	1	42.7
c_079_05	4	49.4
c_079_05	7	55.0
c_079_05	10	57.7
c_079_05	14	60.9
c_079_05	22	66.0
c_079_05	28	70.3
c_079_05	56	79.6
c_079_05	98	91.9
c_079_05	128	96.7
c_079_05	168	100.7
c_079_05	219	107.3
c_079_05	308	115.6
c_079_05	438	122.6
c_079_05	611	128.6

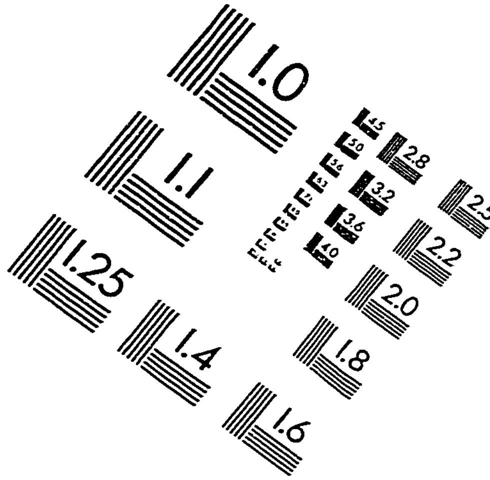
File No.	Days	Experimental (microstrain/MPa)
c_089_02	1472	52.3
c_091_03	1	53.4
c_091_03	2	56.6
c_091_03	3	58.9
c_091_03	7	64.5
c_091_03	14	70.4
c_091_03	28	78.1
c_091_03	56	86.4
c_091_03	90	93.8
c_091_03	180	101.9
c_091_03	365	108.6
c_091_03	730	113.1
c_091_03	820	113.9
c_091_04	1	47.7
c_091_04	2	49.8
c_091_04	3	51.7
c_091_04	7	56.0
c_091_04	14	60.1
c_091_04	28	67.0
c_091_04	56	75.0
c_091_04	90	82.0
c_091_04	180	92.5
c_091_04	365	100.9
c_091_04	730	106.6
c_091_04	770	107.0
c_091_05	1	44.3
c_091_05	2	46.7
c_091_05	3	48.1
c_091_05	7	52.3
c_091_05	14	56.6
c_091_05	28	62.6
c_091_05	56	69.1
c_091_05	90	74.8
c_091_05	180	84.8
c_091_05	365	93.0
c_091_05	730	99.1
c_091_05	750	99.4
c_091_07	1	47.1
c_091_07	2	49.3
c_091_07	3	51.1
c_091_07	7	56.8
c_091_07	14	62.6
c_091_07	28	69.2
c_091_07	56	77.2
c_091_07	90	82.9
c_091_07	180	92.3
c_091_07	365	102.8
c_091_07	730	111.4
c_091_07	878	113.4
c_091_08	1	41.1
c_091_08	2	42.4

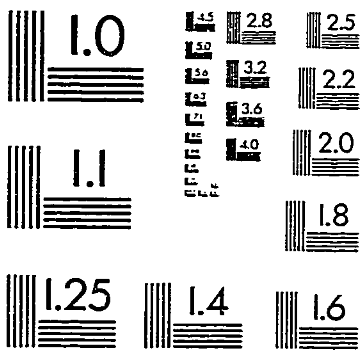
File No.	Days	Experimental (microstrain/MPa)
c_079_05	1859	141.0
c_079_13	1	52.9
c_079_13	3	59.1
c_079_13	7	66.9
c_079_13	14	78.7
c_079_13	28	97.4
c_079_13	49	115.7
c_079_13	70	126.7
c_079_13	98	138.3
c_079_13	126	146.9
c_079_13	168	153.0
c_079_13	198	156.6
c_079_13	238	160.3
c_079_13	289	164.1
c_079_13	378	168.1
c_079_13	508	173.4
c_079_13	681	177.4
c_079_13	1929	189.3
c_079_13	3486	191.6
c_079_14	1	48.7
c_079_14	3	54.1
c_079_14	7	60.0
c_079_14	14	68.6
c_079_14	28	78.7
c_079_14	49	89.6
c_079_14	70	96.6
c_079_14	98	104.4
c_079_14	126	110.6
c_079_14	168	118.6
c_079_14	198	122.0
c_079_14	238	126.9
c_079_14	289	132.4
c_079_14	378	140.4
c_079_14	508	145.7
c_079_14	681	151.4
c_079_14	1929	164.1
c_079_14	3486	168.6

File No.	Days	Experimental (microstrain/MPa)
c_091_08	3	43.7
c_091_08	7	48.2
c_091_08	14	53.6
c_091_08	28	60.0
c_091_08	56	69.1
c_091_08	90	75.9
c_091_08	180	87.3
c_091_08	365	98.1
c_091_08	730	107.1
c_091_08	879	109.3
c_091_09	1	36.2
c_091_09	2	37.2
c_091_09	3	38.2
c_091_09	7	41.3
c_091_09	14	45.0
c_091_09	28	49.6
c_091_09	56	55.6
c_091_09	90	60.1
c_091_09	180	68.1
c_091_09	365	77.1
c_091_09	730	84.8
c_091_09	796	85.1
c_088_39	1	40.4
c_088_39	2	42.9
c_088_39	5	47.7
c_088_39	8	52.3
c_088_39	14	57.2
c_088_39	22	61.5
c_088_39	69	76.0
c_088_39	145	87.4

IMAGE EVALUATION TEST TARGET (QA-3)

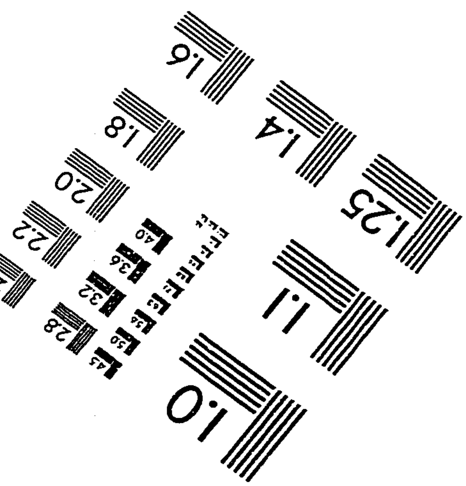


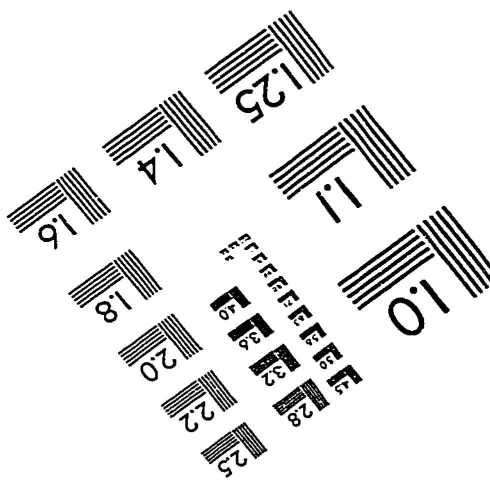




150mm

6″





APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989